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Steam Boilers and Equipment

317 Illustrations

By

C. B. LINDSTROM

AND I.C.S. STAFF

Prepared Under Supervision of

A. B. CLEMENS

DIRECTOR, MECHANICAL SCHOOLS
INTERNATIONAL CORRESPONDENCE SCHOOLS

TYPES OF STEAM BOILERS
BOILER MOUNTINGS
BOILER DETAILS
PIPES AND PIPE FITTINGS
BOILER FURNACES, SETTINGS, AND CHIMNEYS

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PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscripts are prepared by persons thoroughly qualified both technically and by experience to write with authority, and in many cases they are regularly employed elsewhere in practical work as experts. The manuscripts are then carefully edited to make them suitable for correspondence instruction. The Instruction Papers are written clearly and in the simplest language possible, so as to make them readily understood by all students. Necessary technical expressions are clearly explained when introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for more congenial occupations. Usually they are employed and able to devote only a few hours a day to study. Therefore every effort must be made to give them practical and accurate information in clear and concise form and to make this information include all of the essentials but none of the non-essentials. To make the text clear, illustrations are used freely. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title are listed the main topics discussed.

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CONTENTS

NOTE.—This volume is made up of a number of separate parts, or sections, as indicated by their titles, and the page numbers of each usually begin with 1. In this list of contents the titles of the parts are given in the order in which they appear in the book, and under each title is a full synopsis of the subjects treated.

TYPES OF STEAM BOILERS

(Continued)

BOILER MOUNTINGS

BOILER DETAILS, PART 1

PART 2

BOILER DETAILS, PART 2—(*Continued*)

PIPES AND PIPE FITTINGS

PIPES AND PIPE FITTINGS

(*Continued*)

BOILER FURNACES, SETTINGS, AND CHIMNEYS
PART 1

BOILER FURNACES, SETTINGS, AND CHIMNEYS

PART 1—(*Continued*)

PART 2

BOILER FURNACES, SETTINGS, AND CHIMNEYS

PART 2—(*Continued*) *Pages*

TYPES OF STEAM BOILERS

STATIONARY, MARINE, AND LOCOMOTIVE

TERMS AND DEFINITIONS

1. Introduction.—A steam boiler is a closed vessel that, when partly filled with water and heated, is used for the purpose of generating steam. The steam may be used for power, heating, or other purposes. The generation of steam for the development of power subjects the boiler to the most severe strains and requires the greatest refinement of design. The descriptions that follow are devoted to boilers representing the various types in general use.

2. The steam boiler, when in use, is partly filled with water, the space within it being thus divided into two parts, known as the steam space and the water space. The water-line is an imaginary line indicating the level to which the boiler should be kept filled when in service, in order that steam may be generated to best advantage. The *steam space* is the space in the boiler above the water-line. The *heating surface* of a boiler is that part of its surface exposed to the fire, and to the hot gases from the fire as they pass from the furnace to the chimney. The *furnace* is the part of a boiler installation in which the fuel is burned. The *fittings* of a steam boiler consist of such attachments as a steam gauge, water column, and safety valve. The steam gauge indicates the steam pressure in the boiler. The water column is a device composed of a glass tube called a water glass, and three gauge-cocks, called *try cocks,* that are used to determine the height of the water level. The safety valve is attached to the steam space of the

boiler; it automatically relieves the steam pressure when t pressure rises above that for which the valve is set.

3. Classification of Steam Boilers.—Steam boilers may classified according to their form, construction, and use. Th according to their form, boilers are *horizontal* or *vertical;* acco ing to their construction, they are *shell, flue, sectional, fire-tu* or *water-tube boilers;* according to the different conditions unc which they are used, they are designated as *stationary, locon tive,* or *marine boilers.*

A shell, or cylindrical, boiler is one consisting of a pla cylinder closed at both ends. A sectional boiler is one made of a number of cast-iron sections that are assembled and bolt together. This type of boiler is chiefly employed for low-pr sure heating purposes. A flue boiler is made up of a cylindri shell having one or more large flues, or pipes, 6 inches or mc in diameter, surrounded by water and so arranged that t hot gases must pass through the flues. A fire-tube boiler rese bles a flue boiler in principle, but in it a large number of tul take the place of the flues. The tubes are generally $5\frac{1}{2}$ incl or less in diameter. The hot gases pass through these tul just as they pass through the larger flues of a flue boiler. water-tube boiler consists of a number of tubes connected drums and so arranged that water circulates within them wh the heating is done by the hot gases surrounding them. T main features of different types of boilers are frequently co bined, giving rise to a large number of special forms.

STATIONARY BOILERS

SHELL, FLUE, TUBULAR, AND WATER-TUBE TYPES

4. Plain Cylindrical, or Shell, Boiler.—The plain cyl drical, or shell, boiler is now rarely used; but because it is simple construction, it will be described, to bring out certa general features that are common to many boilers. It is r economical on account of its small heating surface. Its adva

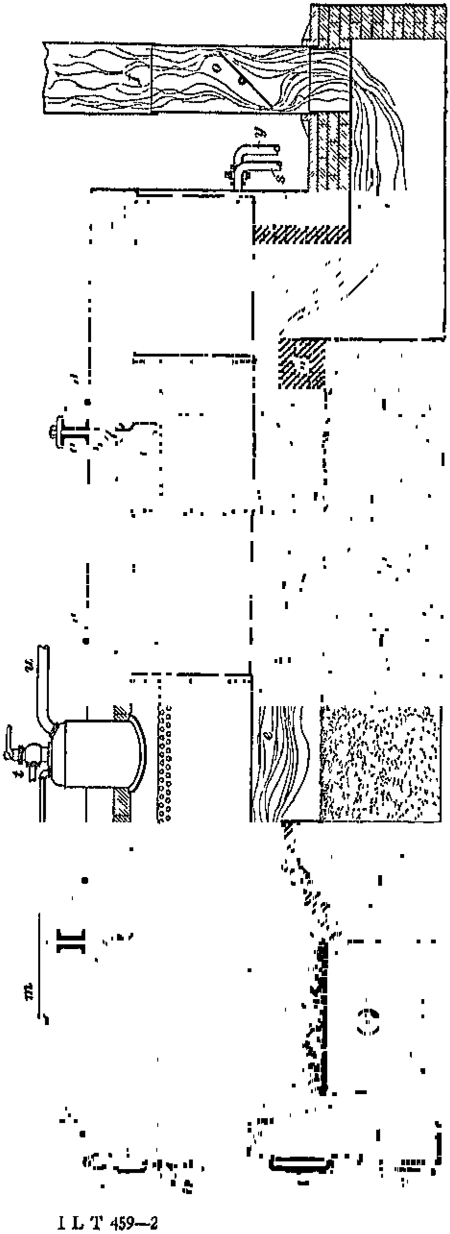


Fig. 1

tages are: Simplicity of construction, low first cost, and the ease with which it may be cleaned and repaired. Its disadvantages are: Low efficiency, which causes waste of fuel, especially if the boiler is pushed beyond easy steaming capacity; large space occupied; its length, which makes it difficult to support without creating excessive and dangerous strains in the sheets and riveted joints, or seams, due to the weight of the boiler and water and the pressure of steam, and to unequal expansion and contraction. These strains change in amount, from tension to compression and vice versa, and may become very dangerous, resulting possibly in a rupture of the boiler.

5. A plain cylindrical boiler, Figs. 1 and 2, consists essentially of a long cylinder, or shell, made of

iron or steel plates riveted together, the girth seams havi single row of rivets and the longitudinal seams a double ro rivets. The shells of boilers of this type are usually fron inches to 40 inches in diameter, and from 20 feet to 40 fe length, although in some cases the length has been mad great as 70 feet. The *heads*, or ends, of the cylinder are ei hemispherical or flat. The former are more generally usec they are stronger than flat heads and require no bracing. manner of suspending the shell is clearly shown. The boil

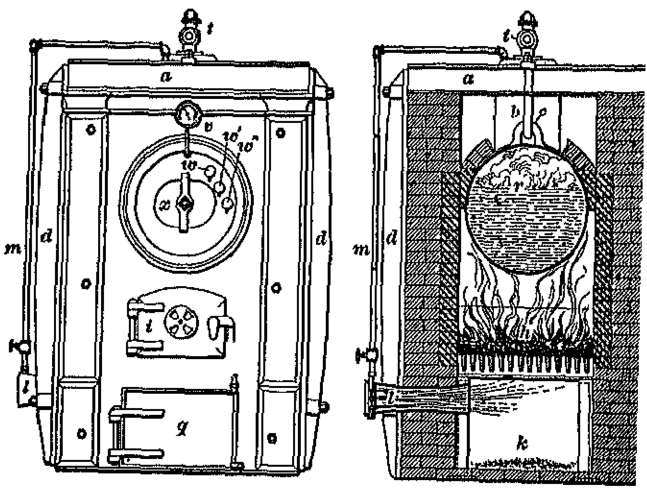


FIG. 2

supported and enclosed by side walls of brick, known as *boiler setting*. The channel beams a are laid across the side walls, and the boiler is suspended from the beams by m of the hooks b and eyes c, the latter being riveted to the s

6. The side walls are supported and prevented from b ling by the *binders*, or *buckstaves*, d, Fig. 2, bolted togethe the top and at the bottom. The buckstaves are cast-iron of T section. The eyes c are placed about one-fourth of length of the shell from each end. This method of suspen allows the shell to expand and contract freely when heatec cooled.

The rear wall is built around the rear end of the shell, as shown in Fig. 1, and continued back to form the chamber *e*, into which opens the chimney or stack *f*. The *boiler front*, shown in Fig. 2, is of cast iron. Fig. 1 shows the front in section. The front end of the shell is partly surrounded by the firebrick *g*, but the weight of the shell comes on the hooks *b*, the rear wall and the firebrick *g* simply keeping the shell in position. The furnace *h*, Fig. 2, is placed under the front end of the boiler shell. The fuel is thrown in through the furnace door *i* and burns on the grate *j*, the ashes falling through the grate into the ash-pit *k*. To insure a supply of air sufficient for a more rapid combustion of the fuel than obtains under natural draft, the furnace is sometimes provided with a blower *l*, consisting of a cylinder leading into the ash-pit *k*, into which is led a jet of steam through the pipe *m*. The steam rushes into the ash-pit with great velocity and carries a quantity of air with it. The pressure of the air in the ash-pit is thus increased, more air is forced through the fire, and the combustion of the fuel is more rapid and complete. It is more usual, however, to use a fan blower instead of a direct steam jet for supplying additional air.

7. Behind the furnace, as shown in Fig. 1, is built the brick *bridge wall n*, which serves to keep the hot gases in close contact with the under side of the boiler shell. As boilers of this type are generally quite long, a second bridge wall *n'* is usually added. The gases arising from the combustion of the fuel flow over the bridge walls *n* and *n'* into the chamber *e*, and escape through the chimney *f*. The flow of the gases is regulated by the damper *o* placed in the chimney. The space *p* between the bridge walls is filled with ashes or some other good non-conductor of heat. The door *q* in the boiler front gives access to the ash-pit for the removal of the ashes. The tops of the bridge walls, the inner surfaces of the side and rear walls, and, in general, all portions of the brickwork exposed to the direct contact of the hot gases, as shown by the dark section lining, are made of a special kind of refractory brick that withstands a very high temperature.

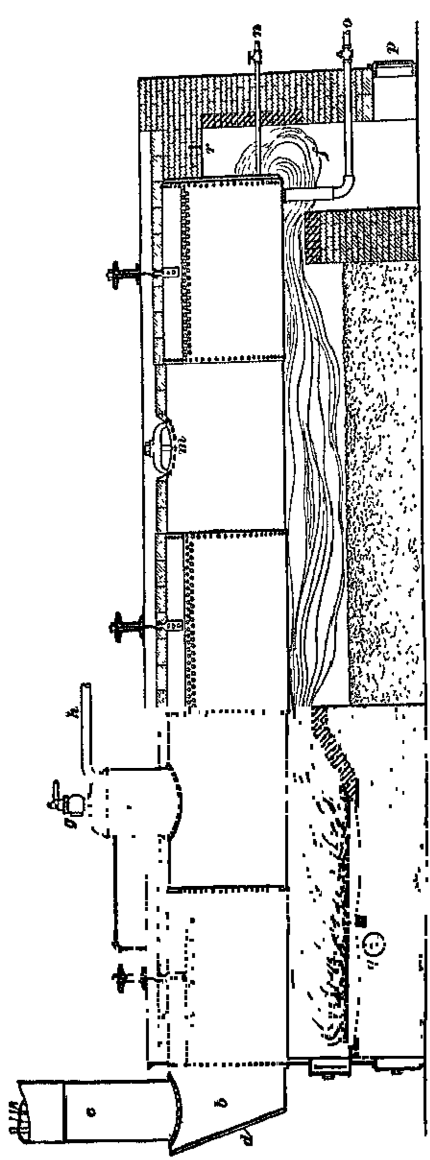


Fig. 3

The brickwork co
ers the upper porti
of the boiler shell
such a manner as
prevent the hot ga
from coming into co
tact with the sh
above the water-lin
Fig. 2. The top
the shell is covered
brickwork or so
other non-conduct
material to prev
radiation of he
Water is forced i
the boiler through
feedpipe *s*, Fig.
from a pump or
injector. When in
eration the wa
stands at about
level *r*, the space al
being occupied by
steam.

8. The saf
valve is shown a
Fig. 1. It opens a
matically when
pressure reaches
point for which
valve is set, and
lows enough stean
escape so that
pressure will not
above the desi
point. Steam is ta
from the boi

through the steam pipe *u*. The steam gauge *v* indicates the pressure of the steam in the boiler; it is attached to a pipe that passes through the front head into the steam space. The gauge-cocks *w*, *w'*, and *w''*, Fig. 2, placed in the front head of the shell, are used to determine the water-level. If any one of the cocks is opened and water escapes, it is evident that the water-line is above that cock, while if steam escapes, the level must be below it. The *manhole x* is a hole in the front head through which a man may enter and inspect or clean the boiler; it is closed by a plate and yoke. To permit

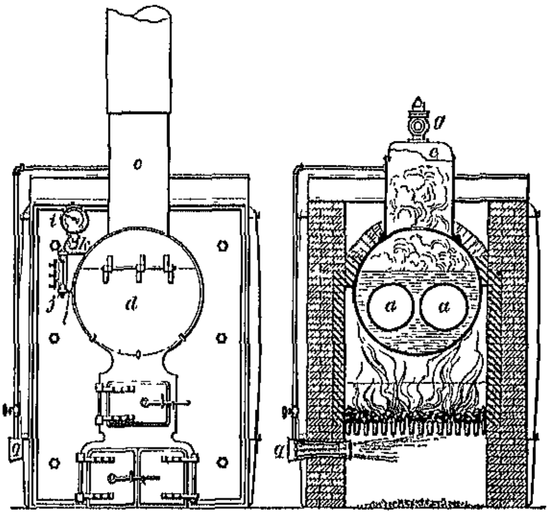


FIG. 4

the boiler to be emptied, it is provided with a *blow-off pipe y*, Fig. 1, through which the water and sediment may be discharged.

9. Flue Boiler.—The flue boiler differs from the plain cylindrical boiler in having one or more large flues running lengthwise through the shell, below the water-line. Such a boiler is shown in elevation and section in Figs. 3 and 4. The ends of the flues *a* are fixed in the front and rear heads of the shell. The front end of the shell is prolonged beyond the head, forming the *smokebox b*, which opens into the smokestack *c*. The

front of the smokebox is provided with a door *d*. The boil shell is also provided with the *dome e*, which forms a chamb where steam may collect and free itself from its entrain water before passing to the engine. The manner of suppor ing the shell and the construction of the furnace and brid walls are the same as for the plain cylindrical boiler. The h gases, however, pass over the bridge walls to the chamber and then back through the flues *a* into the smokebox *b* a out of the stack *c*. It is plain that the heating surface greater than that of the plain cylindrical boiler by the cyli drical surfaces of the flues *a*.

The boiler has a cast-iron front, to which the furnace do and ash-pit doors are attached. The safety valve *g* is attach to the top of the dome. The steam pipe *h* leads from the don to the engine. The steam gauge *i* and gauge-cocks are plac on a column *j* that communicates with the interior of the sh through the pipes *k* and *l*, the former entering the steam spa and the latter the water space. The manhole *m* is placed c top of the shell instead of in the head. The feedpipe is show at *n*, and the blow-off pipe at *o*, both passing through the re wall. Access is given to the rear end of the shell and to t pipes *n* and *o* through the door *p*. This form of boiler ma be provided with a blower, as shown at *q*. The setting is bui and supported in about the same manner as that shown in Fig. The cast-iron *flue plate r* rests on the side and rear walls a supports the brickwork above it.

10. Horizontal Return-Tubular Boiler.—The return-tub lar boiler is so largely used in the United States that it regarded as the standard American fire-tube boiler. Wh properly constructed and operated it is very efficient. It is modification of the flue boiler, the flues being replaced 1 tubes that are smaller and more numerous than the flue usually ranging in size from $2\frac{1}{2}$ to 4 inches in diameter. Tl greater part of the heating surface is provided by the tube Less space is required for the installation of this type, as con pared with the shell boiler or the flue boiler of equal stean generating capacity.

A horizontal return-tubular boiler and its setting are shown in perspective in Fig. 5. A part of the setting and the boiler front *a* have been broken away in order to show the construction clearly. The tubes extend the whole length of the shell and their ends are expanded into holes in the boiler heads and beaded over; sometimes they are welded to the heads after being beaded. A smokebox *b* is formed at the front of the boiler by brickwork, the arch *c* separating the smokebox from the furnace. The connection from the top of the smokebox to the chimney is generally made by a sheet-iron flue, although

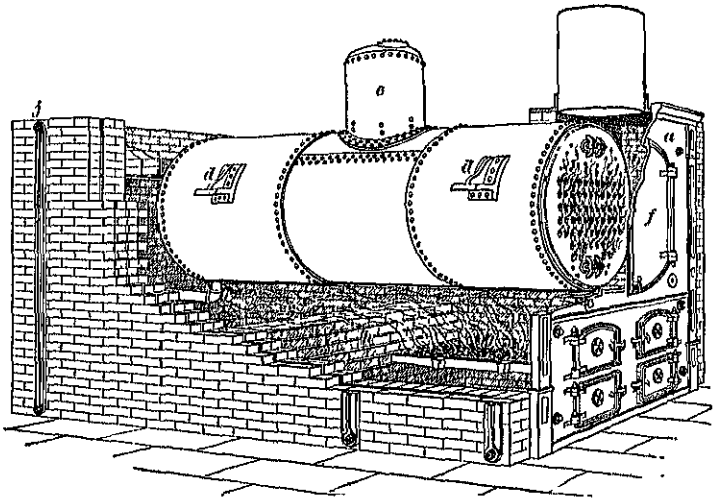


FIG. 5

occasionally a brick flue leading to the chimney is built on top of the boiler. The boiler is supported on the brick walls of the boiler setting by the brackets *d* riveted to the shell. These brackets usually rest on cast-iron plates let into the brickwork, rollers being set between the brackets and plates to allow the boiler to expand freely. A dome *e*, which increases the steam space, may be provided, though it is usually left off and an internal dry pipe is used instead. The walls are built and supported by buckstaves in practically the same manner as those previously described.

11. Firebrick is used for all parts of the wall exposed to the fire or heated gases. The fittings are not shown in Fig. 5. The safety valve is placed on top of the dome, and the pressure gauge and gauge-cocks are placed on the front. The manhole may be either in one of the heads or on top of the shell, although sometimes manholes are provided in both ends and in the top of the shell. The feedpipe may enter the front head, while the blow-off pipe *i* is placed at the bottom of the shell, at the rear end. Access is given to the rear end of the boiler through a clean-out door. The tubes are made accessible for cleaning out, etc., by large doors, as *f*, in the boiler front. The furnace and grates *g* are placed under the front end of the boiler. The gases pass over the bridge *h*, along under the boiler into the chamber at the rear, then back through the tubes to the smokebox *b*, and thence to the chimney.

12. Horizontal return-tubular boilers are installed with either *flush fronts* or *overhanging fronts*. These fronts are made of cast iron, or of steel plate formed into the shape for the doors, door frames, and rings that are used for supporting the smokebox doors. In the flush front setting, Fig. 5, the boiler does not extend beyond the boiler front. It is set back of the cast-iron front *a*, so that the gases have a large smoke space *b* to travel through before entering the stack.

The general arrangement of a return-tubular boiler having an overhanging front is shown in Fig. 6 (*a*). In this case the boiler has a steel smokebox *a* that extends beyond the steel front *b*. In such construction the front tube-sheet is installed so that the flange of the tube-sheet *c* extends outwards, as shown in view (*b*). This drawing further illustrates the relative arrangement of the tubes *d* and the diagonal braces *e* that support the flat section of the tube plate, above the tubes, commonly referred to as the *tube-head segment*. The stays are riveted to the boiler shell and tube head. The nozzle *f* is pressed from steel plate, having at the bottom a flange by which the nozzle may be riveted to the shell plate. The upper end of the nozzle has a flange to which the safety valve is bolted. To provide an entrance to the shell for inspection, for clean-

ing, and for the removal of tubes and their installation in case repairs are needed, the boiler is fitted with a manhole *g*, at

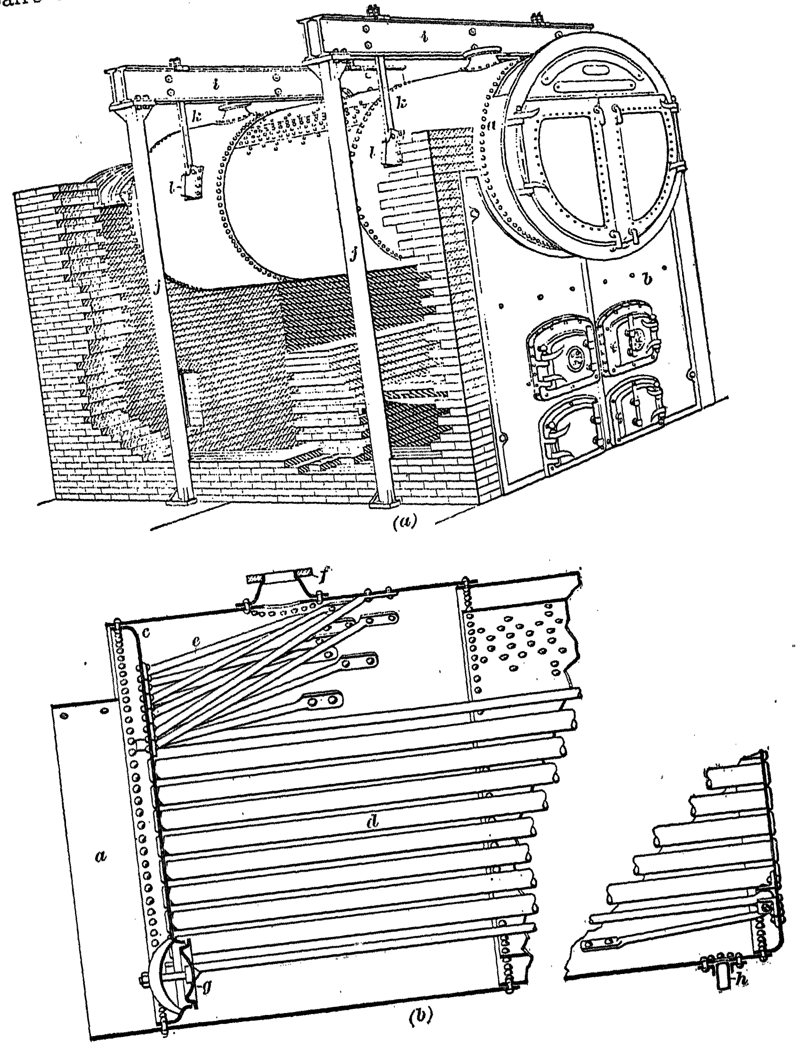


FIG. 6

the bottom of the front tube head. A manhole is also installed at the top of the boiler shell. At the rear of the boiler is

located a drain, or blow-off, *h*, that is employed for removing the water from the boiler periodically and for cleaning purposes. The boiler shown in view (*a*) is suspended from I beams *i* that are supported by cast-iron columns *j*. Suitable hanger rods *k* and hanger straps *l* are employed in suspending the boiler. This method of setting a boiler is more flexible than is obtainable with the use of brackets. The rear end is

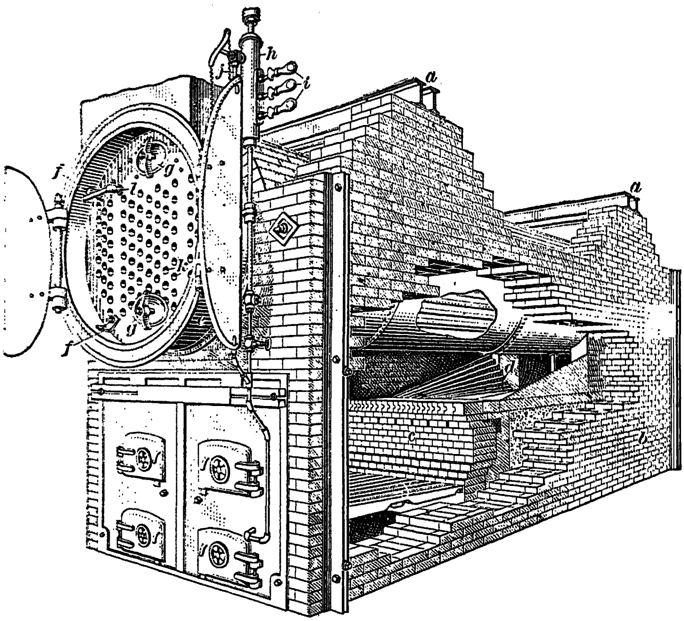


FIG. 7

set from 1 inch to $1\frac{1}{2}$ inches lower than the front end to facilitate draining off the water through the blow-off at the rear.

13. Uniflow Return-Tubular Boiler.—The uniflow boiler is a modification of the horizontal return-tubular boiler. In Fig. 7 is shown a typical installation, with the boiler setting. The boiler is suspended from I beams *a* by suitable hangers. A brick setting *b* surrounds the boiler and forms the sides of the furnace. The furnace setting consists also of a bridge wall *c*, and an inverted arch *d* that runs from the bridge wall

to the rear of the boiler. This feature in the arch construction increases the velocity of the gases and causes them to flow in contact with the bottom of the shell plate of the boiler. The extension smokebox *e* is a steel-plate ring, fastened to the front head of the boiler by lugs *f* that are bolted to both the smokebox and the boiler head. This construction permits the removal of the smokebox, if repairs are required on the boiler head, or in case some of the tubes must be removed and new ones installed. To provide means for cleaning, inspecting, and

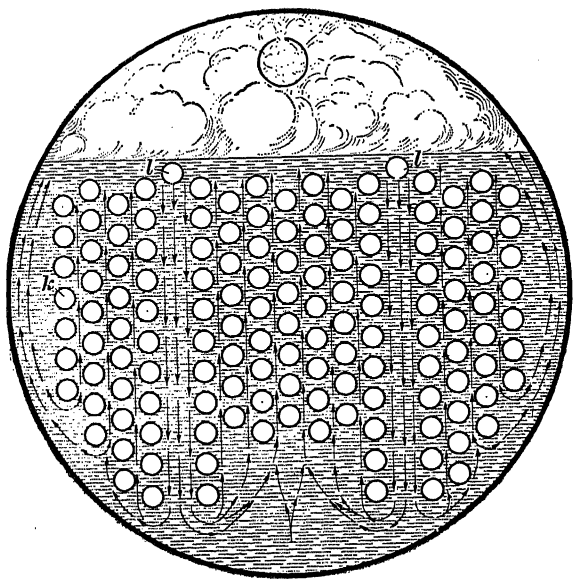


FIG. 8

repairing the boiler, manholes *g* are installed above and below the tubes. A water column *h*, with gauge-cocks *i* and a gauge glass *j*, is conveniently placed at the front of the boiler, so that the water level in the boiler can be readily seen.

14. The tubes *k*, Fig. 7, shown also in the cross-section, Fig. 8, are arranged in parallel vertical rows, but are staggered in the horizontal alinement. They are grouped in three divisions, thus forming an arrangement called *tube nests*, or *tube banks.*

The water is fed into the boiler through the connection *l*, placed on the side of the front head above the tubes. The feedwater is discharged downwards between the center and outer tube banks. Circulation of the water and steam is indicated by the arrows. Steam rises directly from the heating surface to the steam space and the cooler water flows downwards between the tubes and replaces the hotter water carried away by the upward circulation. The boiler derives its name from this provision for the circulation of the water.

15. Robb-Mumford Boiler.—The boilers so far described have the furnace outside of the boiler itself, and hence are said

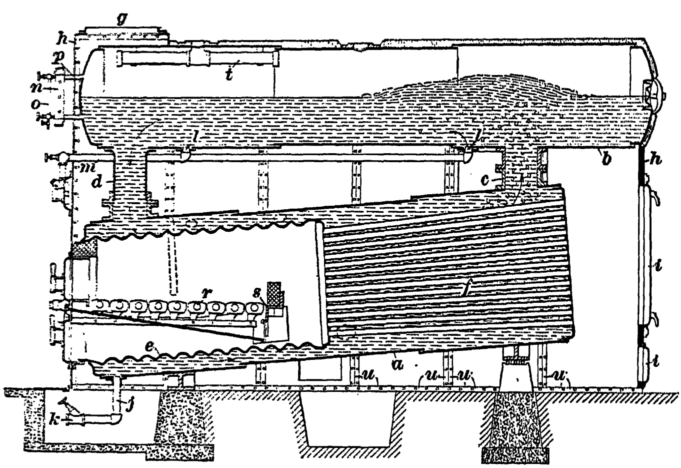


FIG. 9

to be *externally fired*. Many boilers are in use, however, in which the furnace is inside the boiler; such boilers are referred to as being *internally fired*. The Robb-Mumford boiler, shown in section in Fig. 9, is an example of an internally fired horizontal boiler. It consists of two cylindrical drums *a* and *b* connected by the cylindrical nozzles, or necks, *c* and *d*, one at each end. The lower drum *a* contains a cylindrical furnace *e* fitted at one end with a furnace front containing a fire-door and an ash-pit door, and at the other end with a tube-sheet into which are expanded the tubes *f*. The tubes are also expanded into the

rear head of the lower drum *a*. The lower drum is inclined about 1 inch per foot, this inclination promoting the circulation of the water in the boiler, and also facilitating the complete emptying of the boiler, as the blow-off pipe is attached to the lower end of the lower drum *a*. The upper drum *b* serves as a steam drum. The gases of combustion pass from the furnace through the tubes *f* and return about the lower and upper drums, passing then to the smoke outlet *g* at the front of the boiler. A steel casing *h*, containing suitable doors *i* that give access to the interior, surrounds both the upper and lower drums.

16. An important factor in the operation of a boiler is the circulation, or movement of the water. When the water is heated, it expands, becomes lighter, and rises to the surface. In the boiler shown in Fig. 9, the heated water strikes the sloping upper surface of the lower drum *a* and flows toward and up through the neck *c*. When the water begins to boil, the steam bubbles up through the water, forming a mixture of steam and water. This condition increases the rapidity with which it rises through the neck *c*, and the more rapid the boiling, the more rapid the circulation becomes. When the mixture reaches the surface of the water, the steam separates and accumulates in the drum *b*, above the water level. As the mixture rises through the neck *c*, water takes its place in the lower drum, and the neck *d* is provided for this purpose. Therefore, as the water and steam rise through the neck *c*, the water descends from the upper to the lower drum through the neck *d*, thus completing the circulation.

17. The blow-off *j*, Fig. 9, is located at the front of the boiler, and when the blow-off valve *k* is opened the water and steam will be carried through a pipe to the outside of the boiler room or into a sewer. The purpose of the bottom blow-off is to remove mud and sediment that collect at the bottom of the boiler. Feedwater enters through the openings *l*, and the outside water pipe *m* is led to the discharge end of a feedwater pump or injector. The water column *n* and the gauge glass *o* are joined to the boiler by the pipes *p*. The upper pipe enters the steam space and the lower pipe the water space. This

arrangement of the devices and piping makes it possible to determine the height of the water level in the boiler at all times. The rocking grates *r* in the boiler furnace are supported at the rear by an arch *s* and at the front by an angle-iron support. A pipe *t*, called the *dry pipe*, is connected to the main steam outlet. It is of cylindrical shape, from 4 to 6 inches in diameter, having a number of holes along the top, through which steam enters in its travel to the steam outlet. The purpose of the dry pipe is to remove water held in suspension in the steam. The casing that surrounds the boiler is built of steel plate with angle-iron stiffeners *u*, and is made in sections that are bolted together. The inside of the casing and the top of the steam drum are lined with non-conducting material.

18. Clyde, or Dry-Back, Boiler.—The Clyde boiler shown in Fig. 10 is entirely self-contained, requiring no brick setting. It was originally designed for marine use, but on account of the small space it occupies it is used in many stationary steam plants. This type of boiler has a very large amount of heating surface in proportion to its grate area. The boiler consists of a large cylindrical shell *a*, its ends being closed with flat heads *b*. The corrugated furnace *c*, commonly referred to as the *Morison corrugated furnace*, is riveted to the front and rear heads, which are flanged inwards for this purpose. Tubes *d* extend from head to head, thus providing heating surface and a means for conveying the gases from the furnace to the uptake or smokestack *e* that connects with the chimney *f*. The smokebox is also commonly called a *breeching*. The flat heads are stayed by end-to-end stays *g* called *through stayrods*, which prevent bulging of the heads. The remaining parts of the flat heads are supported by the tubes, which are expanded and beaded over, and by the furnace flue. The furnace is formed within the flue, and comprises the grate *h*, the ash-pit *i*, and the bridge *j*. The gases of combustion flow to the rear into the combustion chamber *k* and then pass through the tubes to the front and into the uptake *e*.

19. The combustion chamber *k*, Fig. 10, is formed by a thin cylindrical shell attached to the rear end of the boiler, and

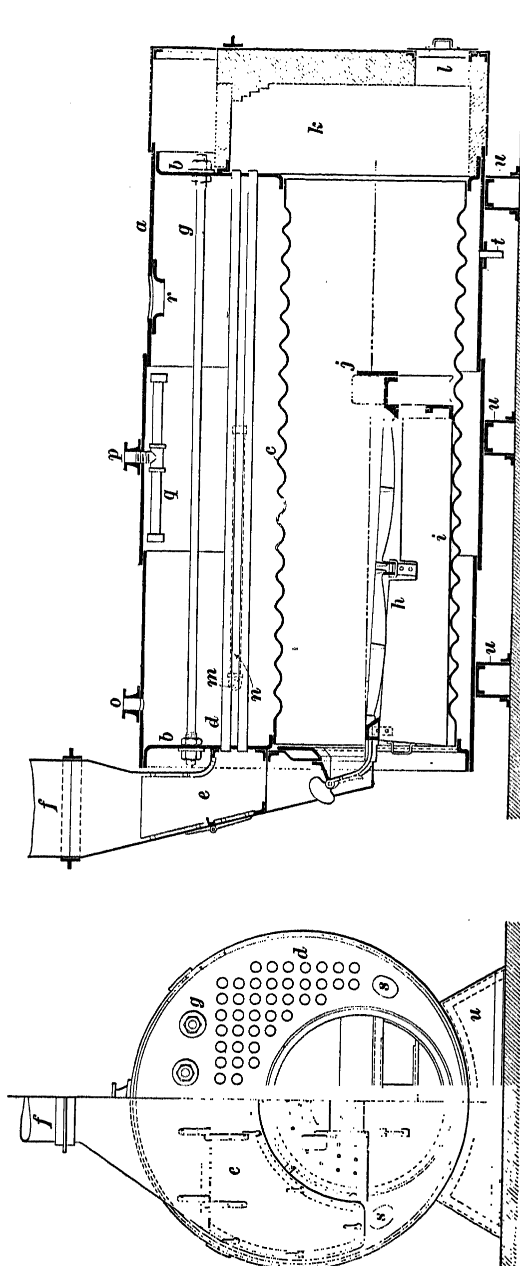


Fig. 10

is lined with firebrick or thick asbestos millboard, which is light and is not affected by intense heat. The back plate is removable, giving access to the rear ends of the tubes. A door *l* gives access to the combustion chamber for the removal of ashes and soot and for the purpose of examination and repair. The feedwater enters the boiler at *m* and, passing through the internal perforated feedpipe *n*, is discharged downwards alongside the shell in small streams. The various fittings, such as the steam gauge, water column, and safety valve, are not shown in the illustration. The water column and steam gauge would be located conveniently for reading the steam pressure and for determining the water level. The safety valve would be bolted to the nozzle *o*, and the steam pipe to the nozzle *p*. The steam is collected by the dry pipe *q*, which is effective in removing water mixed with the steam. The manhole is placed in the shell at *r*, and handholes are arranged in the front head, at *s*. The blow-off connection is placed at *t*. The boiler is supported by structural members *u*, made of angle iron and plate, and so arranged that each one carries approximately the same weight.

20. Vertical Tubular Boiler.—The vertical, or upright, fire-tube boiler may be considered as a modification of the locomotive type placed on end, and, in common with that type, is self-contained. It has the advantage that it requires less floor space than the horizontal return-tubular type; and, being self-contained, the outer shell can be made as heavy as desired for any working pressure. Vertical boilers are used to supply steam for hoisting engines, power shovels, and other installations requiring a small, compact boiler. The large sizes are employed for power purposes in some of the large power plants; but as a rule the vertical boiler is rather inefficient and hard to keep free from soot. Leakage of upper tube ends often occur, owing to forcing.

21. A common form of vertical boiler is shown in Fig. 11. It consists of a vertical shell, at the lower end of which is the firebox *a*. The lower rim of the firebox and the lower end of the shell are separated by a wrought-iron ring *b*, commonly

called a *mud-ring*. Both shell and firebox are riveted to the ring, the rivets extending through both plates and the ring. For the larger sizes of boiler, the shell is made up of a number of cylindrical sections that are riveted together; or, as in the illustration, where a large firebox is required, the lower section of the boiler shell is joined to the smaller upper section by a taper course *c*. By this arrangement a large water space is obtained at the bottom of the shell between the tubes and the shell plate; also, it is easy to get at the tubes *d* and the tube-sheet *e*, commonly called *crown sheet,* for inspection and cleaning purposes. Entrance to the boiler is gained through the manhole *f*. Handholes *g,* conveniently arranged for cleaning purposes, are placed just above the tube-sheet and the mud-ring.

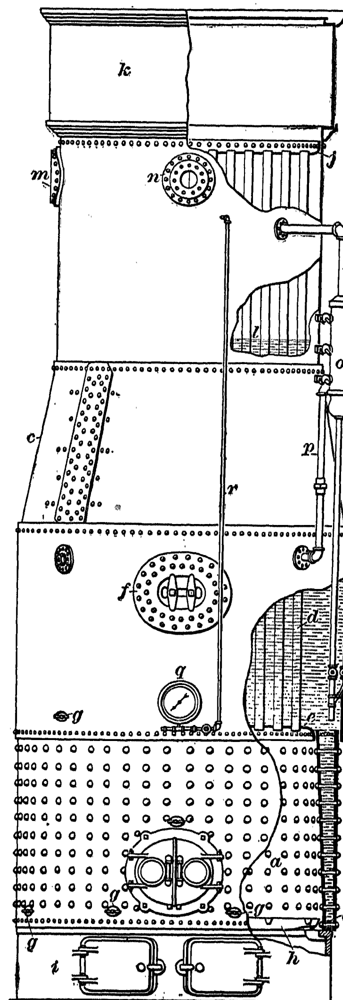


FIG. 11

22. The lower outer shell and the firebox, Fig. 11, are stayed together with threaded stays, called *staybolts,* which are screwed into both shell plates, so that the ends extend about $\frac{3}{16}$ inch from the boiler plates. To increase the holding powers of the stays, they are headed at the ends. The boiler shell and the grates *h* rest on a cast-iron base *i* that forms the ash-pit. The vertical tubes extend from the top tube-sheet *j* to

the crown sheet of the firebox. The tubes serve as stays to strengthen the flat surfaces of the tube-sheets, and convey the gases from the firebox to the chimney or stack connection *k*. The tubes pass through the steam space and are, therefore, not surrounded by water, as the highest water level is usually at the line *l*. This arrangement is considered a bad feature, because the tubes are liable to become overheated and collapse, when the boiler is forced. On the other hand, the steam temperature in the steam space is increased and drier steam is obtained, as the heat from the tubes slightly superheats the steam; that is, it heats the steam to a higher temperature than that of the water from which the steam is formed. The main steam-pipe connection is made to the flange *m* and the safety valve is bolted by a suitable fitting to the flange *n*. The water column *o*, with its gauge glass and cocks, is connected by the pipes *p* to the steam and water spaces of the boiler. A steam gauge *q* is connected to the steam space by a drop pipe *r* so that the gauge is brought to a suitable position for reading the pressure.

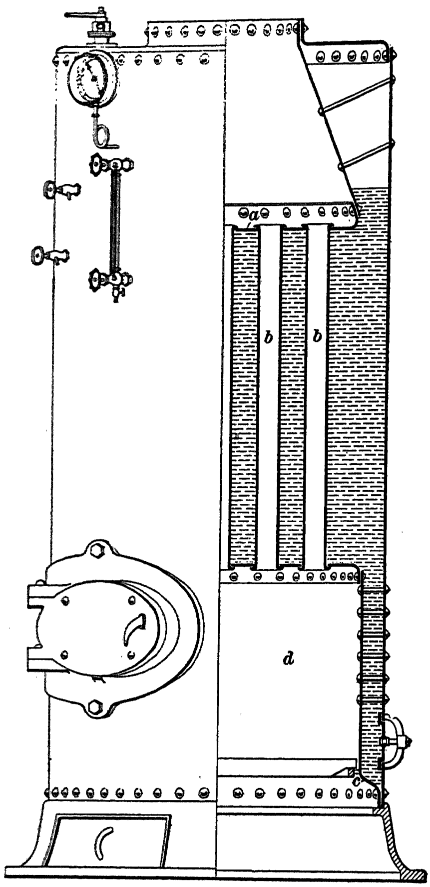


Fig. 12

23. The *submerged-head vertical boiler,* shown in Fig. 12, takes its name from the arrangement of the tube-sheet *a* and the tubes *b*. The tube-sheet *a* forms the base of the smokebox, and the upper ends of the tubes are expanded into it. By the use of the conical smokebox the tubes are entirely surrounded by water. Aside from the submerged head and the construction used in riveting the firebox and the outer shell together, the boiler is similar to the type shown in Fig. 11. The firebox *d,* Fig. 12, is flanged at its base so that the plate forms a compound curved section *c,* called an *ogee flange.* By making the flange of this shape, the necessary water space between the firebox and the outer shell is obtained. This space is usually referred to as the *water leg* of the boiler. Boilers made in this way are generally used for low working pressures and for light duty, as for hoisting engines. Vertical boilers of the form shown in Fig. 11 are employed in power plants, as such boilers are much larger and can, therefore, produce greater amounts of steam for power.

24. Manning Boiler.—The Manning boiler is used extensively throughout the New England States. In general, it is a modification of the plain vertical boiler having a tapering course. The details of its construction are shown in Fig. 13. The firebox *a* is a steel cylindrical shell, riveted to the tube-sheet or crown sheet *b* at the top, and to the mud-ring *c* at the bottom. An outside shell plate *d* surrounds the firebox and the two are connected by the staybolts *e*. To connect the upper shell *f* and the lower shell *d* of the boiler, an ogee flange *g* is employed. The advantage of the ogee connection is that it provides a larger firebox area without a corresponding increase in the diameter of the shell *f,* and does not require staying, being self-supporting on account of the double curvature of the plate. The tubes are of standard size, $2\frac{1}{2}$ inches in diameter, and are installed in lengths up to 20 feet. All tubes are held in the tube-sheets by expanding or rolling. The ends of the tubes extend usually from $\frac{3}{16}$ to $\frac{1}{4}$ inch beyond the head. They are turned down around the tube holes and beaded; that is, the tube ends are turned over to form rounded flares, or

lips, called beads. The beads prevent the tube ends from burning off and add strength to the staying qualities of the tubes.

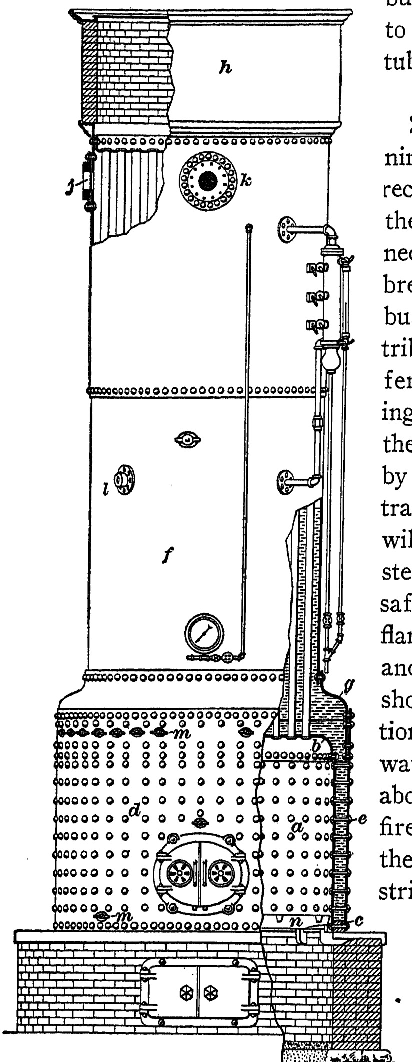


FIG. 13

25. The gases in the Manning boiler, Fig. 13, travel directly from the firebox through the tubes to the smoke connection *h*. The small tubes break up the products of combustion and give a wider distribution of the heat and transfer it rapidly to the surrounding water. The upper ends of the tubes are not surrounded by water, and the heat that is transmitted through these parts will superheat the steam. The steam outlet is at *j*, and the safety valve is connected to the flange *k*. The water column and steam gauge are also shown in their proper positions on the boiler. The feed-water connection *l* is well above the crown sheet of the firebox, being so placed that the colder water does not strike the heated plates of the firebox. Handhole openings *m* are provided in the shell above the crown sheet of the firebox and just above the mud-ring. They are used when it is necessary to clean out the mud and scale that collect on the tube-sheet and the mud-ring. The grates *n* rest

on a support incorporated with the brick foundation that forms the ash-pit. The vertical type of boiler requires considerable head room for its installation; but as compared with other boilers of the same size or capacity it occupies less ground space. To prevent heat losses by radiation from the outer shell, a covering of asbestos or magnesia should be applied.

SEMI-PORTABLE AND PORTABLE BOILERS

26. Distinctive Features.—It is somewhat difficult to draw a sharp line of demarcation between stationary, semi-portable, and portable boilers. Generally speaking, a *stationary boiler* is one that is permanently set in brickwork, as, for instance, the horizontal return-tubular boiler.

A *semi-portable boiler* is one that is arranged to be shipped on skids from place to place. It may, of course, be set on a permanent foundation; but it is then spoken of as a stationary boiler of the semi-portable type.

A *portable boiler* is a boiler mounted on wheels and that can be hauled by horses or tractors from place to place. Boilers of this kind are used by building contractors, quarrymen, threshermen, oil-well operators, etc. They are especially suitable to meet conditions requiring a temporary power plant capable of being moved about at a small expense.

Both semi-portable and portable boilers are generally of the firebox type, of either the vertical or the modified locomotive types.

27. Locomotive-Type Boiler.—The internal-firebox boiler of the locomotive type, shown in Fig. 14, is a modification of the larger types used for locomotives in railroad practice. With the exception of the horizontal return-tubular boiler, the locomotive-type boiler is used to a larger extent than any other type of fire-tube boiler. It is employed for tractors, road rollers, threshing machinery, and power plows, and for stationary purposes. The boiler consists of a cylindrical shell *a* that is riveted to a steel-plate firebox containing the furnace *b*. The firebox, which may be made in various shapes, is composed of a

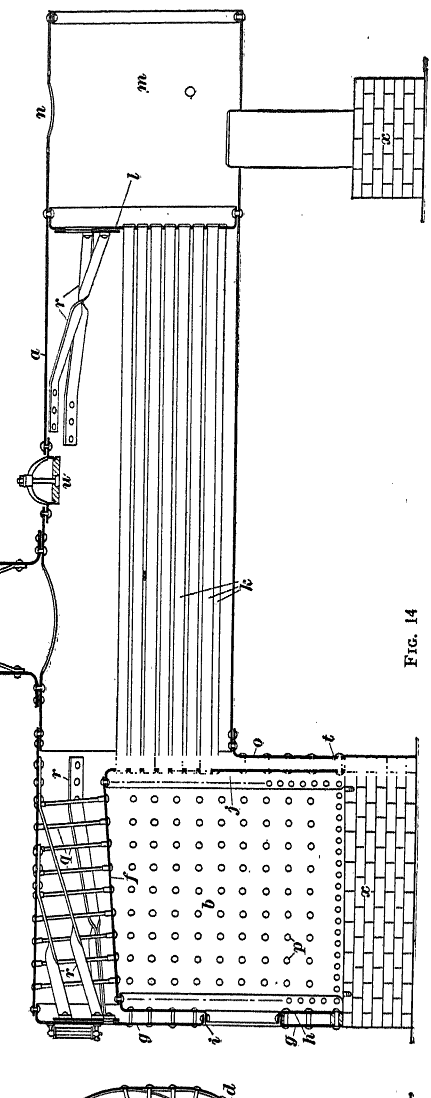


FIG. 14

continuous inner sheet *c* and an outer sheet *d*, called *wrapper sheets*. These sheets are arranged to leave water spaces, or water legs 2 to 3 inches in width at the sides of the firebox. The upper plate section *e* of the outer wrapper sheet is called the *roof*, and the top section *f* of the inside wrapper is known as the *crown sheet*. The end section of the outer wrapper is closed by a flanged head *g*, called the *back head*, and the inside wrapper sheet with a flanged head *h*, known as the *door sheet*. Both of these heads are flanged, as shown at *i*, to form the door opening, or *door ring*. The forward end of the inside wrapper sheet is closed with a flanged head *j*, called the *firebox tube-sheet*, from which a series of tubes *k* extend to the circular tube-sheet *l*. The front of the shell *a* is extended beyond the tube-sheet *l* to form the smokebox *m*. An opening *n* is cut in the smokebox for the stack connection. A flanged sheet *o*, known as the *throat sheet*, is so made that it connects the flat sides of the outer wrapper sheet of the firebox and the shell *a*.

28. As the flat sides of the furnace, Fig. 14, are not self-supporting, they must be braced or stayed. This is done by staybolts *p*, which are riveted over at both ends, so as to upset the stays in the threaded holes and thus produce steam-tight work. The stays *q* are known as *radial stays*, or *crown stays*, and support the roof and the crown sheet of the firebox. The flat surfaces of the back head *g* above the door ring, and that above the tubes of the front tube-sheet *l*, are stayed by diagonal braces *r*, called *crow-foot braces* on account of the shape of their ends. Circular clean-out openings *s* are provided above the mud-ring *t* and the crown sheet for washing out the boiler. The mud-ring *t* closes the water legs at the bottom of the fire-box, being riveted to both the inner and outer wrapper sheets.

Entrance to the boiler for inspection, repairs, and cleaning is made by removing the manhole cover *u*. A dome *v* is attached to the shell *a*, but in some constructions it is riveted to the roof sheet. It is preferable, however, from the view-point of staying the firebox, to have the dome on the shell. The dome head, being flat, is not self-supporting, so it is stayed with crow-foot braces *w* that are riveted to the dome head and near the base of

the dome. In some constructions, threaded stayrods are screwed into the dome head and the shell plate under the dome; but in such a case the dome opening would not be cut out entirely as is shown in the illustration. A number of circular holes would be drilled in the shell plate, to allow free circulation of steam into the dome, but leaving sufficient material between the holes for installing the screw stays. The feedwater may be introduced at any convenient place in the boiler shell below the water-line, usually at the coolest section of the boiler. This boiler is of the semi-portable type that may be moved about on skids, and then mounted on a brick founda-

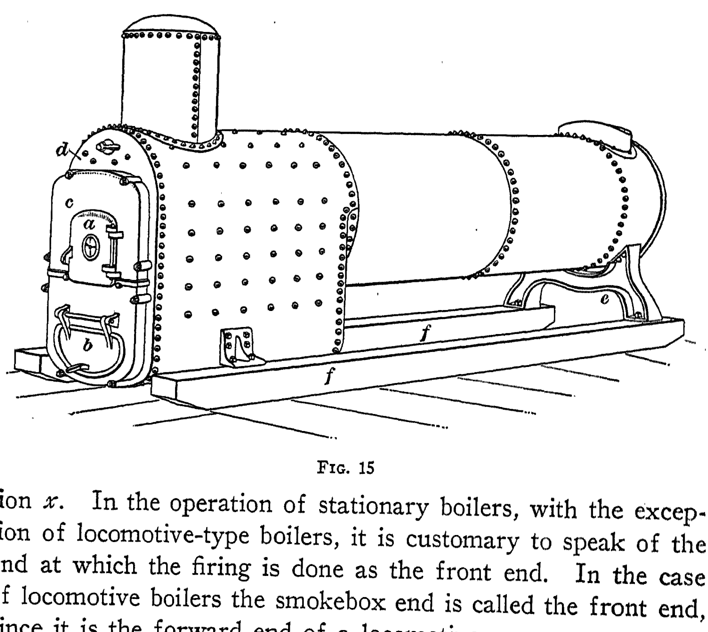


FIG. 15

tion x. In the operation of stationary boilers, with the exception of locomotive-type boilers, it is customary to speak of the end at which the firing is done as the front end. In the case of locomotive boilers the smokebox end is called the front end, since it is the forward end of a locomotive.

29. Wet-Bottom Firebox Type.—A perspective view of a semi-portable boiler of the firebox type is shown in Fig. 15. The bottom of the firebox, instead of opening into an ash-pit, is closed by a continuation of the water legs, and hence the furnace is entirely surrounded by water. A boiler thus constructed is said to be *wet-bottomed*. In the particular design shown, the

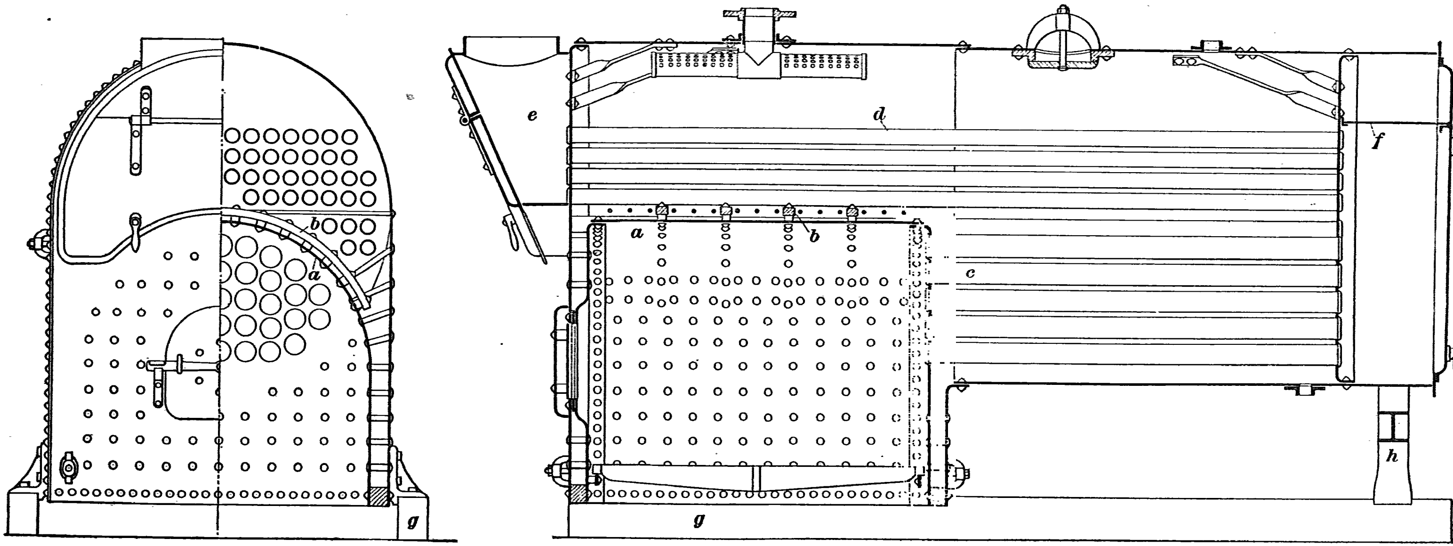


Fig. 16

fire-door *a* and ash-pit door *b* are attached to a cast-iron front *c* which, in turn, is bolted to the back head *d*; with this construction the firebox wrapper sheet is riveted directly to flanges formed on the back head, there being no furnace end or door sheet. The cylindrical part of the boiler is supported by a cast-iron cradle *e*. For convenience of shipment, the boiler is mounted on skids *f*, which may also serve as a temporary foundation. Some wet-bottom boilers have an ash-pit door in the center of the bottom instead of in the back head.

30. Pennsylvania Boiler.—In Fig. 16 is shown a form of boiler that is a combination of a firebox and a return-tubular boiler, and which is known as the Pennsylvania boiler. The firebox, or furnace, has a semicircular crown sheet *a*, which is stayed by solid crown bars *b* having a rectangular cross-section. The water legs are stayed by screw stays, as in locomotive boilers. The gases of combustion pass through the large, short, lower tubes *c* to a combustion chamber forming an extension of the cylindrical part of the boiler, and then return through the small, long tubes *d* to the smokebox *e*, whence they discharge into the chimney. A baffle plate *f* is fitted to the combustion chamber to prevent the hot gases from coming into contact with the upper part of the tube-sheet, which part is not covered by water.

The boiler is self-contained; that is, it requires no elaborate setting. It has the advantage over the locomotive boiler of having a much greater depth of water over the crown sheet, and the heated gases have a longer tube travel, thus making it possible to use a greater amount of the heat from the products of combustion. For convenience in shipment, the boiler is mounted on skids *g*, the cylindrical part of the boiler being supported in a cast-iron cradle *h*, which is utilized when the boiler is set permanently on a foundation.

HORIZONTAL WATER-TUBE BOILERS

31. Advantages of Water-Tube Boilers.—The boilers previously described have been of the types in which the water surrounds the tube or tubes, the flame and hot gases being inside the tube. In the water-tube boiler this condition is reversed; the water is inside the tubes, which are surrounded by the fire and hot gases. Water-tube boilers are commonly known as safety boilers, because an accident to any one tube or fitting does not necessarily involve the destruction of the whole boiler. They are extensively used for both land and marine service. The demand for very high steam pressure has led to the development of the water-tube boiler.

32. It is maintained that the heating surface in water-tube boilers is much more effective than an equivalent area of surface in the ordinary tubular boilers. In water-tube boilers, the direction of the circulation is well defined and there are no interfering currents. The circulation is rapid and over the entire boiler, keeping it at a nearly constant temperature and tending to deposit all the sediment at the lowest point. The water is divided into small bodies, the boilers steam quickly, and are sensitive to slight changes of pressure or condition of the fire. The arrangement of a water-tube boiler is such as to form a flexible construction, any member being free to expand without unduly expanding any other member. This very important feature tends to prolong the life of the boiler.

There is considerable difference in the amount of soot collected in a fire-tube and on a water tube. Soot accumulates within a fire-tube, and it may become filled, while the water tube holds the soot only on the top surface. Water-tube boilers are of sectional construction, and hence may be transported and erected more readily than other types.

33. Babcock and Wilcox Boilers.—The Babcock and Wilcox boiler is built in two classes, namely, the longitudinal-drum type and the cross-drum type. These types are made with vertical or inclined tube headers, which are formed in pressed steel or are iron castings, depending on the working

pressure for which the boiler is constructed. The longitudinal drum is standard, although, where head room is a factor, the cross-drum type is built to meet the requirements.

In Fig. 17 are illustrated the details of construction of the longitudinal-drum Babcock and Wilcox boiler. It consists of one or more horizontal drums *a*, dependent on the size of the

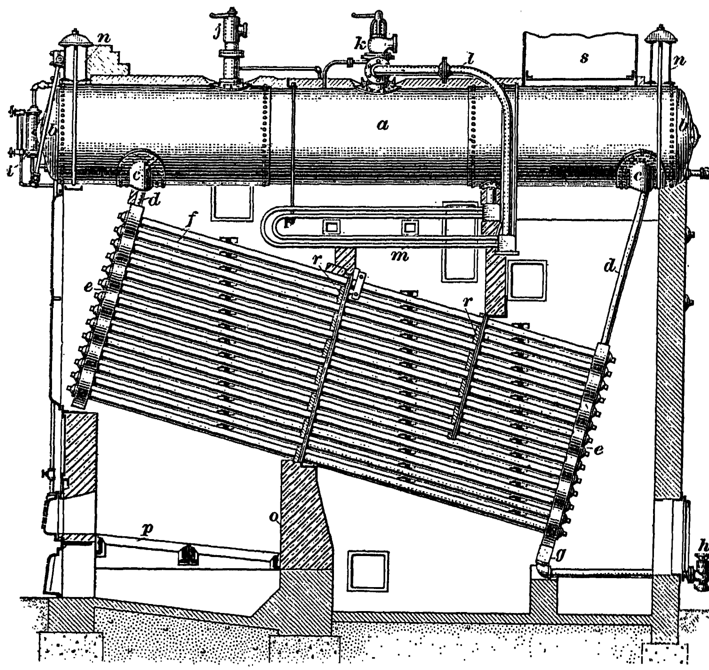


FIG. 17

boiler and its capacity, usually made of three cylindrical courses riveted together with single-riveted seams. These particular seams are called *girth seams,* or *circumferential seams.* The riveted joints running lengthwise of the drum are called *longitudinal seams.* They are made by butting the longitudinal edges of the drum sections together and covering the joints with outside and inside plates, which are riveted together with the shell plate. Joints made in this way are called *butt joints.* The heads *b* close the ends of the drum.

34. The drum heads are pressed to the form shown in Fig. 18, with a manhole opening *a*. The flange of the manhole acts as a stiffening ring and provides additional strength to the plate around the opening. The stiffening ring is faced off to form a seat for the manhole cover-plate. Flat raised seats are also pressed in the head at *b* for the water column and at *c* for the feedwater connection. Cross-tube boxes *c*, Fig. 17, are riveted to the drum of the boiler. These tube boxes are pressed to the form shown in Fig. 19 and shaped so as to fit snugly to the curvature of the drum. Tube holes are bored in the bottom face of the box, for the attachment of the tubes *d*, Fig. 17, that connect the tube headers *e* and the drum *a*, thus providing the means for circulation of steam and water in the front and rear tube headers. The tube headers *e* are curved along the sides, being so shaped that adjoining header sections fit snugly together and permit a staggered arrangement of the water tubes. The sectional view, Fig. 20, shows the outline of the header section, with tube holes and handholes. The latter are placed directly opposite the tube holes and are of sufficient size to permit cleaning and renewal of the tubes. A section is shown of the handhole plate *a* and the crab *b*. The nut *c* is used in bringing the handhole plate *a* to its seat so as to form a steam-tight joint.

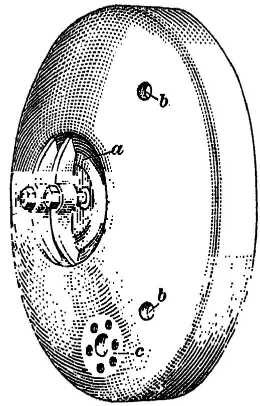


Fig. 18

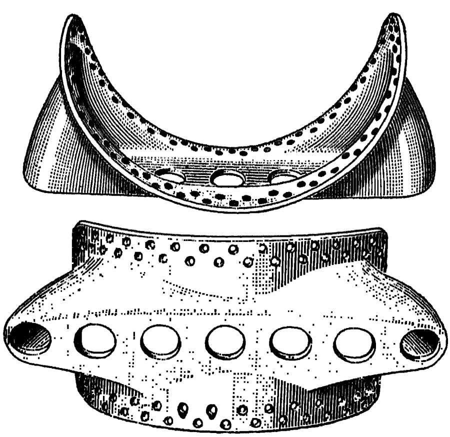


Fig. 19

35. The *mud-drum g,* Fig. 17, to which the header *e* is connected, is a steel box 7¼ inches square, and of sufficient length to connect the tube-header sections. It collects mud and sediment that settle at the bottom of the vessel. The sediment is removed through handhole openings in the drum or is blown out through the blow-off connection *h*. The pressure gauge and the water column *i* are connected to the drum *a*. A safety valve *j* is attached to the drum and another safety valve *k* is connected to the main steam pipe *l* that leads from the superheater *m*.

The superheater is constructed of pipe coils and headers through which the steam from the steam space of the drum *a* is circulated. The superheater is set directly in the furnace, and is subjected to the hot gases. If at any time no steam should be drawn from the boiler, the superheater would become overheated. The safety valve *k* is provided to prevent this condition. It is set at a pressure slightly below that of the safety valve *j*, and when the pressure rises it will open and permit some steam to flow through the superheater.

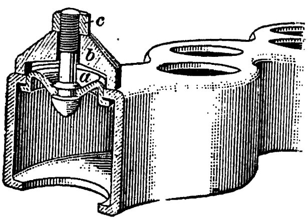


FIG. 20

36. Feedwater is introduced through the front drum head *b*, Fig. 17, and is carried back to the rear of the drum. It flows downwards in the rear header *e*, then through the tubes *f* to the front header *e*, and upwards through this header to the drum *a*. The water that is not transformed into steam again follows the circulation. The steam that is liberated in the drum *a* is stored in the steam space and is drawn off either through a dry pipe or through the superheater *m*.

The method of supporting the longitudinal-drum boiler shown is to suspend the rear and front ends from steel **I** beams *n*, which rest on columns, thus forming a structural frame support independent of the brickwork in the setting. This method allows for expansion and contraction without affecting the boiler or setting. This type of boiler, in common with most boilers

of the water-tube type, requires a brick setting to form the furnace and combustion chambers. The boiler furnace is built in the setting at the front of the boiler under the tubes. At the bottom of the furnace, extending up to the tubes, is built a bridge wall *o*, which forms a support for the grates *p*. The bridge wall prevents the gases and flame from traveling directly back to the rear of the boiler. By means of the walls *r*, built in between the tubes, and commonly called *baffles*, or *baffle walls*, the products of combustion are compelled to travel in a zigzag path around the tubes to the smoke outlet *s*, thus increasing considerably the gas travel in the boiler furnace.

37. Boilers of the cross-drum type are constructed similarly to the longitudinal-drum type. The main difference is in the arrangement of the upper drum, which is placed above and across the rear header. Horizontal circulating tubes are used to connect the drum and the front header to provide means for the circulation of water and steam. Vertical tubes connect the drum and the rear tube header.

38. Heine Water-Tube Boiler.—A boiler differing in many respects from that shown in Fig. 17 is the Heine boiler, illustrated in Fig. 21. It consists of a large main drum *a*, above and parallel to the nests of tubes *b*. Both drum and tubes are inclined to the horizontal at an angle that brings the water level to about one-third the height of the drum in front and to about two-thirds the height in the rear. The ends of the tubes are expanded into the large wrought-iron water legs *c*. These legs are flanged and riveted to the shell, which is cut out for about one-fourth of its circumference to receive them, the opening being from 60 to 90 per cent. of the cross-sectional area of the tubes. The drum heads form segments of a sphere, and therefore do not need bracing. The water legs form the natural support of the boiler, the front water leg being placed on a pair of cast-iron columns *d* that form part of the boiler front, while the rear water legs rest on rollers, shown at *e*, that can move on a cast-iron plate embedded in the rear wall. These rollers allow the boiler to expand freely when heated.

39. The Heine boiler is enclosed by a brickwork setting in the usual manner. The bridge wall *f*, Fig. 21, made largely of firebrick, is hollow, and has openings in the rear to allow air to pass into the chamber *g* and mix with the furnace gases. In the rear wall is the arched opening *h*, which is closed by a door and further protected by a thin wall of firebrick. When it is necessary to enter the chamber *g*, the wall at *h* may be removed and afterwards replaced. The feedwater is brought

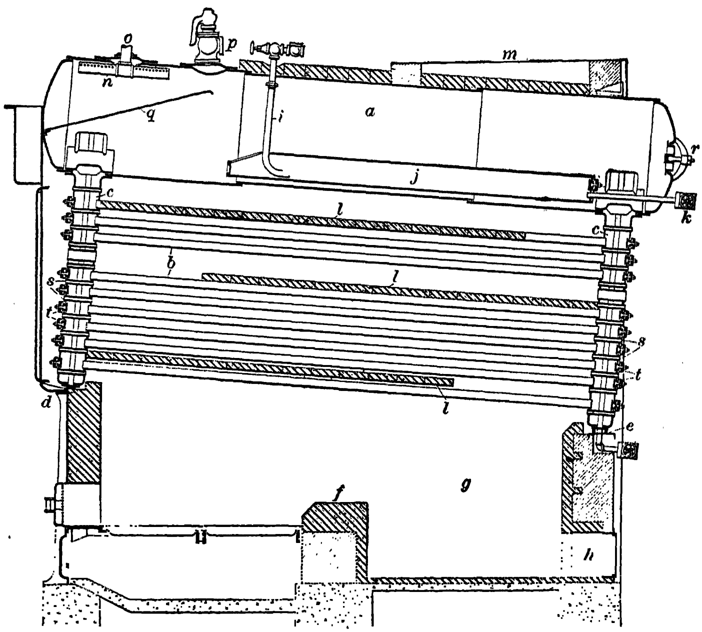


Fig. 21

in through the feedpipe *i*, which passes through the top of the drum. As the water enters, it flows into the mud-drum *j*, which is suspended in the main drum below the water-line and is thus completely submerged in the hottest water in the boiler. This high temperature is useful in causing the impurities contained in the feedwater to settle in the mud-drum *j*, from which they may be blown out through the blow-off pipe *k*. The water passes back out of the open end of the mud-drum and circulates in the same direction as in the boiler shown in Fig. 17.

40. Layers of firebrick *l*, Fig. 21, are laid at intervals along the rows of tubes and act as baffle plates, forcing the furnace gases to pass back and forth over the tubes. The gases finally escape through the chimney *m* placed above the rear end of the boiler. To protect the steam space of the drum from the action of the hot gases, the drum in the vicinity of the chimney is protected by firebrick, as shown. The steam is collected and freed from water by the perforated dry pipe *n*. The

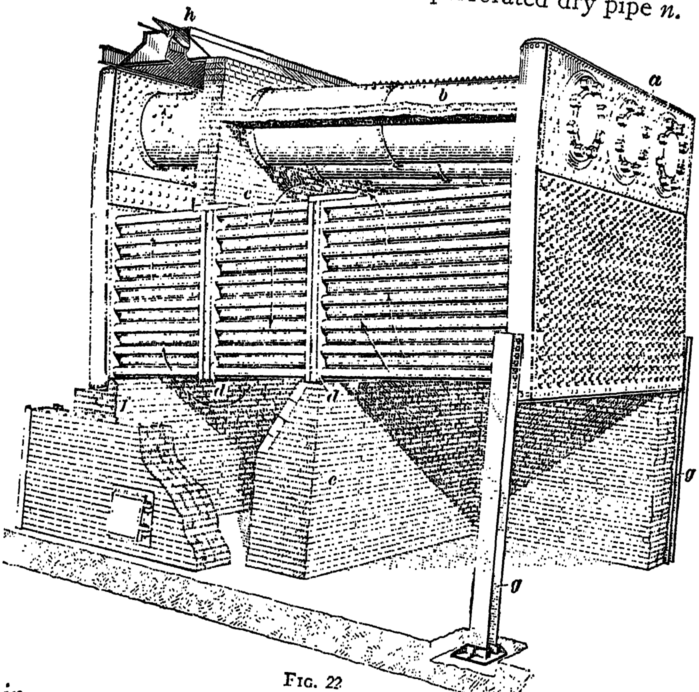


FIG. 22

main steam pipe is attached at *o*, and the safety valve is shown at *p*. In order to prevent a spray of mixed water and steam from spurting up from the front header and entering the dry pipe, a deflecting plate *q* is placed in the front end of the drum. A manhole *r* is placed in the rear head of the drum. The flat sides of the water legs are stayed together by the staybolts *s*, which are made hollow to permit a small steam pipe to be inserted, forming a blower to clean soot from the outside of the

tubes. In front of each tube a handhole t is placed to give access to the interior of the tube. When a group, or battery, of several boilers is used, additional steam drums are placed parallel to the drums a.

41. Edge Moor Water-Tube Boiler.—The Edge Moor water-tube boiler, shown in Fig. 22, is also made up of tubes, tube headers, and drums. The distance feature in its construction is the tube header a, which is carried above the

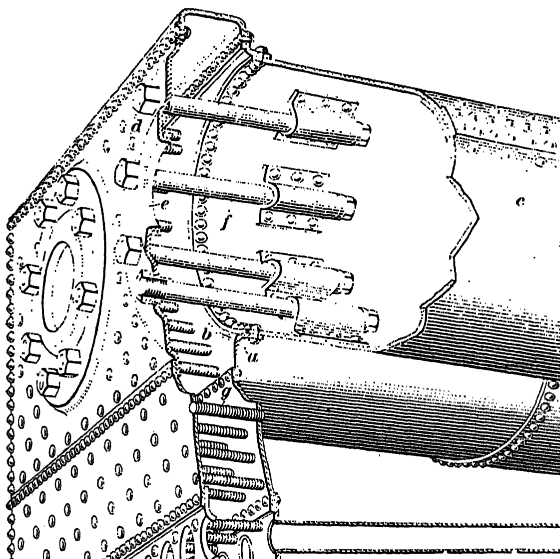


FIG. 23

drums b, thus providing additional steam and water space. The section, Fig. 23, shows the tube-header details and how the drum is arranged and stayed to the header connection. A flange a is turned on the header plate b, into which the drum c is set and riveted. To reinforce the outer sheet d around the manhole opening e, the stays f are installed. All flat plates of the headers are stayed with screw staybolts g, which are screwed into the inner and outer sheets and riveted over. Opposite each tube is placed an elliptical handhole. The hand-

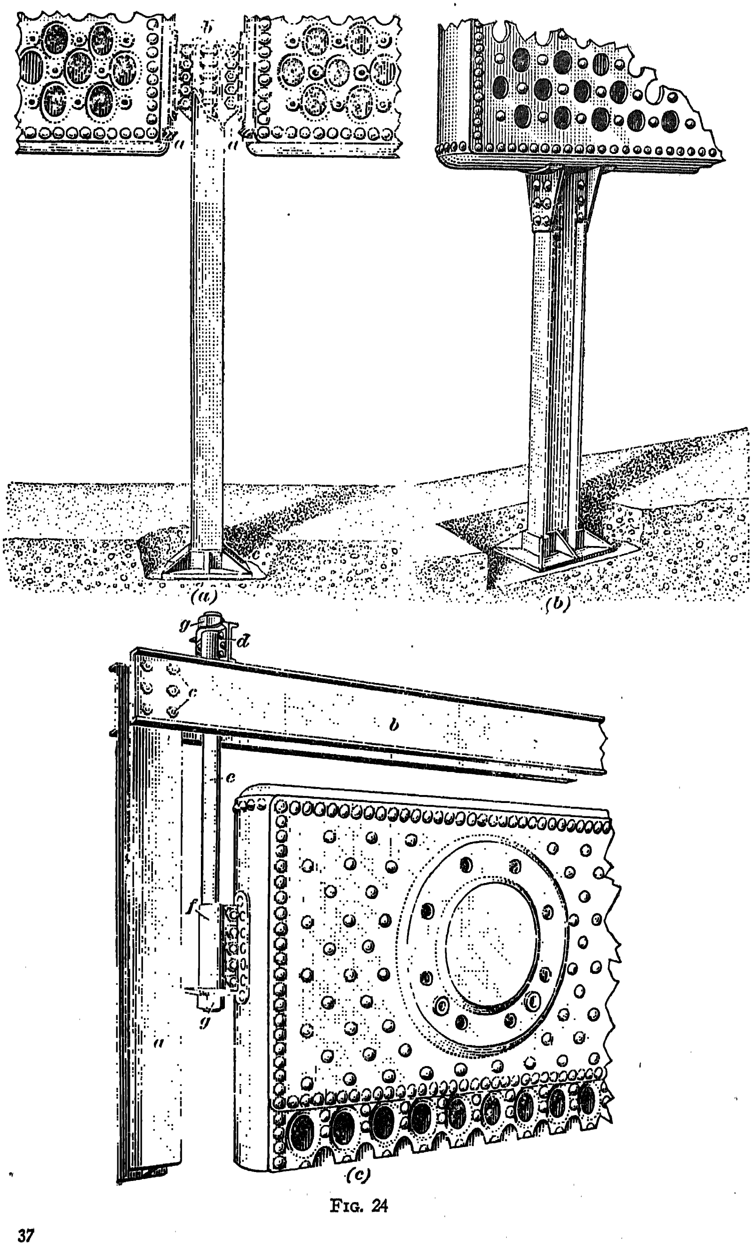


FIG. 24

hole plates are removable through their own openings; and through these openings the tubes are cleaned or repaired. Fig. 22 shows the relative arrangement of the tube headers *a*, drums *b*, tubes *c*, baffles *d*, and bridge wall *e*, and a section of the boiler setting *f* with the front structural supports *g*. The grates and other details are not shown. The grate sections would be placed in front of the bridge wall, under the high end of the boiler. The fuel gases travel in the direction of the arrows, upwards around the front tube section, downwards about the middle tube section, and upwards around the rear tube section to the smoke breeching *h*.

42. The Edge Moor boiler is supported by columns or suspended from overhead beams. Column supports for the headers are shown in Fig. 24 (*a*) and (*b*). View (*a*) shows an **H** column used for supporting the front of a battery of boilers. It is placed between the headers and bolted to angle clips *a* that are fastened to the headers. Angles *b* are riveted to the web of the **H** column. A foundation plate *c* is embedded in the concrete floor that forms a base for the column. The saddle support, view (*b*), is placed at the rear of the boilers, under the back headers. The suspension method of supporting the boilers is illustrated in view (*c*). Either **H** or **I** beams *a* form the column supports, and channels *b* form the cross-beams. The channels are bolted together at each end by bolts *c*, and spacers or sleeves are placed between the backs of the channels, through which the bolts pass. The spacers keep the channels apart and in alinement. A special steel sleeve *d* rests on the channels. A hanger bolt *e* passes through the sleeves *d* and *f*, and an adjusting nut *g* facilitates adjusting the boiler so that the headers hang plumb with the supports.

VERTICAL WATER-TUBE BOILERS

43. Bigelow-Hornsby Water-Tube Boiler.—The difference between the Bigelow-Hornsby boiler and those already described is in the tube arrangement and the shape of the tube headers. A typical installation, represented in Fig. 25, is com-

posed of a steam and water drum *a*, connected to the tube headers *b* by circulating pipes *c*. The headers *b* are cylindrical and the upper head *d* of each header is flanged and riveted to the shell. A standard manhole opening, 11 inches by 15 inches, is flanged in each head. The bottom heads in the lower tube head-

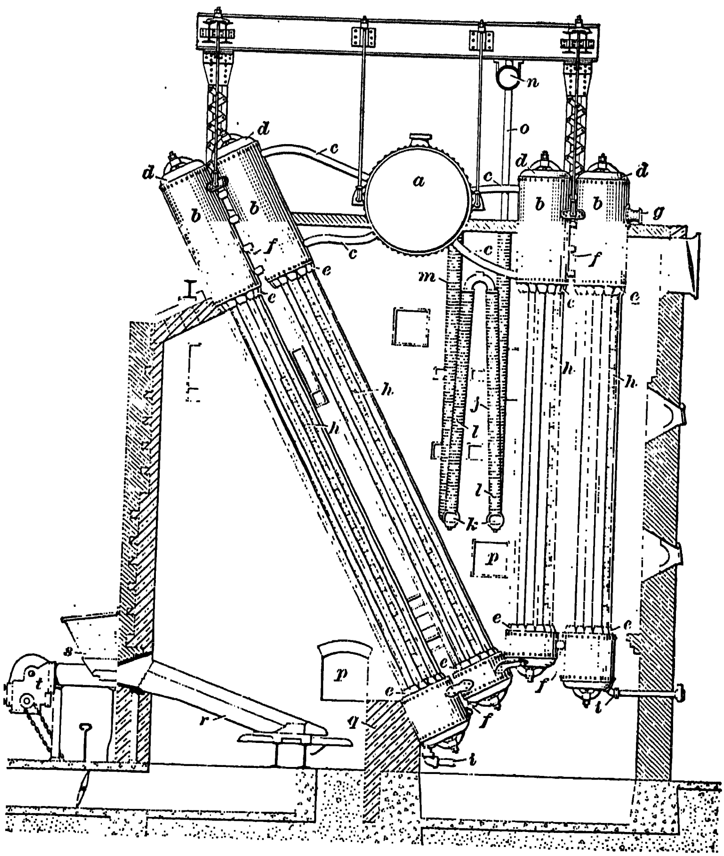


Fig. 25

ers are made in the same way, and standard manholes permit access to the drums to inspect, clean, and repair the tubes or header plate. The manholes eliminate the use of handhole plates. Tube plates *e* are shaped by a hydraulic press and dies to form suitable seats for the tubes. Each nest of tube headers

is connected to the adjoining set by circulating tubes *f*, giving the required means for circulation of steam and water. A nest of 21 tubes directly connects the upper and lower tube headers.

Feedwater enters the top rear header through the connection *g*, passes down the rear tubes, and is then carried by the circulation up the tubes in the front tube units. It thus passes through the rear tube units, which are in contact with the cooler gases of combustion, before entering the forward units where the heating surfaces are directly in contact with the fire and hottest gases. Baffle plates *h* are placed between the tubes to change the gas travel.

44. The lower drum headers, Fig. 25, collect the mud and other sediment that settles when the water is heated to a high temperature. Bottom blow-off connections *i* are installed in the lowest part of the drum heads for the purpose of blowing out mud and sediment. Beneath the main drum *a* is shown a superheater *j* made of pipe bent to a **U** shape, with the legs connecting headers *k*. To protect the wrought pipes or tubes from the corroding effect of the gases, cast-iron cover-plates *l*, called grids, are fixed around the superheating tubes. Steam is drawn from the drum *a*, passes down the pipe *m*, and circulates through the **U** tubes of the superheater to the main steam piping *n*, which is connected to the superheater by the pipe *o*.

Owing to the length of the drum and tube-header units, the setting must have high headroom. The tube-header units are suspended from structural members installed outside the boiler setting. Suitable clean-out and inspection doors *p* are provided for the convenient removal of refuse that collects back of the bridge wall *q*, and for the inspection of the boiler sections, which must be made periodically. The furnace in this installation is constructed for firing the fuel with a mechanical device *r*, called a *stoker*. The coal hopper is shown at *s* and the propelling machinery at *t*. The grates of the stoker are inclined.

45. Stirling Water-Tube Boiler.—A well-known type of bent-tube stationary boiler is the Stirling water-tube boiler, shown in Fig. 26. It consists of a lower drum *a* connected with three upper drums *b* by three sets of nearly vertical tubes *c*.

The upper drums are connected by the curved tubes *d*. The curved forms of the different sets of tubes allow the different parts of the boiler to expand and contract freely without strain. The boiler is enclosed in a brickwork setting, which is provided with various openings *e*, so that the interior may be inspected or repaired. The boiler is suspended from a framework of wrought-iron girders, not shown. The bridge wall *f* is faced

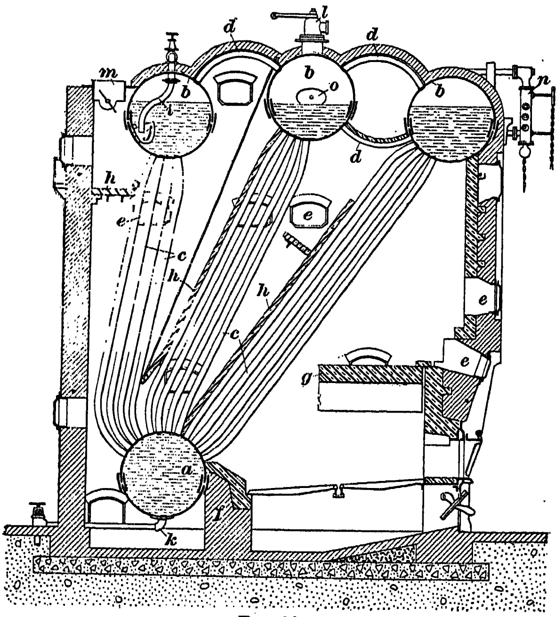


FIG. 26

with firebrick, and is built in contact with the lower drum *a* and the front nest of tubes. A firebrick arch *g* is built above the furnace, and this, in connection with the brick baffles *h*, directs the course of the heated gases, causing them to pass up and down between the tubes. The arch *g* becomes heated to a white heat, promoting combustion, and heating the incoming air when the furnace doors are opened, thus protecting the boiler from being chilled when the fires are being cleaned or stoked.

46. The feedwater enters the rear upper drum through the pipe *i*, Fig. 26, passes into the trough *j*, and descends through the

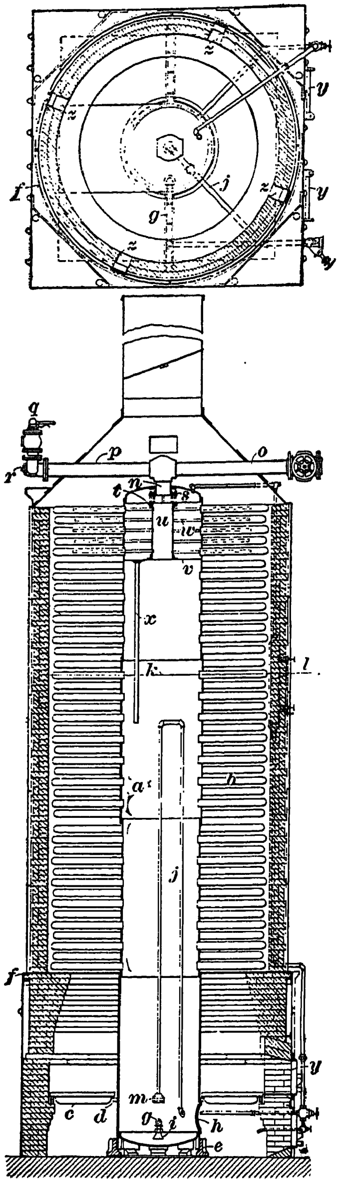


FIG. 27

rear nest of tubes to the drum *a*, which acts as a mud-drum and collects the sediment from the water. From the drum *a* the water passes upwards through the two forward sets of tubes and is vaporized as it rises, the steam passing from the front drum to the middle drum through the upper set of curved tubes *d*, while the unvaporized water circulates between the front and middle drums through the lowest set of curved tubes *d*, and thus the heated water does not again mingle with the comparatively cold water in the drum *a*. The steam collects in the upper drums *b*. A blow-off pipe *k* permits the removal of the sediment. The steam pipe and the safety valve *l* are attached to the middle drum. The chimney connection *m* is located behind the rear upper drum. The water column *n*, with its fittings, is placed in communication with the front upper drum. Each drum is provided with a large manhole *o*.

47. Hazelton Water-Tube Boiler.—The Hazelton boiler, sometimes called the *porcupine boiler*, because of the rather peculiar arrangement of the water tubes, is shown in Fig. 27. It consists of a vertical shell *a*, to which a large number of radial

tubes *b* are attached, having their inner ends expanded in the tube holes in the shell and their outer ends closed. The grates *c* surround the cylinder near the bottom. The inner ends of the grate bars rest on a ring *d* supported by brackets riveted to the shell, and the outer ends rest on a plate on the brickwork enclosing the ash-pit. The boiler rests on a circular cast-iron base *e* placed on a masonry foundation. The boiler and furnace are enclosed in brickwork that supports the chimney. The brickwork is built up square to the height of the lower tubes and circular above that point. The furnace brickwork is encased in sheets of steel riveted to angle irons at the corners and reinforced by angle and **T** bars riveted to the casing. An air space is provided between the brick lining and the casing to decrease the radiation.

48. The top of the furnace wall, Fig. 27, supports a circular steel plate *f*, on which is built the brick setting above the furnace. The circular brick setting is enclosed in sections of sheet steel bolted together. The firebrick lining of the furnace is built so as to slope inwards at the top and deflect the flame against the standpipe of the boiler. The lower end of the standpipe below the grates forms a settling chamber, or mud-drum. It is fitted with a blow-off pipe *g* and a manhole *h* opposite one of the ash-pit doors. The blow-off pipe enters the mud-drum below the grate and terminates in a cone-shaped nozzle *i*. The feed-pipe *j* enters the shell below the grate and extends vertically nearly to the water-line *k l* in the boiler. It then passes downwards and delivers the water through a spraying nozzle *m* at the level of the grate.

49. The steam outlet is through a heavy nipple *n*, Fig. 27, screwed through the center of the top head of the steam drum. A **T** on the outer end of the nipple provides openings for the steam pipe *o* and a pipe *p* leading to the safety valve *q*, but this arrangement is not to be recommended; for, when the safety valve blows, the rush of steam to the outlet may cause water to be drawn along with the steam to the engine or turbine, and may result in a wrecked cylinder or stripped turbine blades. It is good practice to keep the steam outlet and the safety-valve outlet separate and as far apart as possible. A handhole *r* is

located on the end of the pipe below the safety valve, which is uncovered to afford ventilation to the interior of the boiler when it is necessary for a man to enter it. The nipple *n* terminates at its lower end in a flange *s*, to which is bolted a blank flange *t* at a distance of several inches. This blank flange closes the top of a short length of large pipe *u* suspended from it.

50. A diaphragm plate *v*, Fig. 27, is attached to the lower end of the pipe *u* and the shell of the boiler and closes the annular space between them. From the central pipe *u* a large number of small pipes *w* radiate horizontally and extend into the boiler tubes nearly to their outer ends. The steam flows from the central pipe through the small pipes into the boiler tubes, and thence backwards into the top of the steam drum, whence it passes out between the two flanges *s* and *t*. A drip pipe *x* is suspended from the diaphragm and extends a short distance below the water level in the boiler. Two firing doors *y* are located at one side of the furnace, and several doors are conveniently located in the brick setting, so that an examination can be made of the exterior of the boiler shell and tubes.

51. Wickes Water-Tube Boiler.—Another form of vertical water-tube boiler, known as the Wickes boiler, is shown in Fig. 28. It consists of two cylindrical drums *a* and *b* joined together by a number of long straight tubes *c*. The tubes are separated by a baffle plate *d* of firebrick, passing through the center of the tube nest, thus dividing the tubes into two banks. The boiler drums are of the same diameter, but differ in height and in the arrangement of the convex heads *e*. The upper, or steam, drum *a* is closed at the bottom with a tube-sheet *f*. The drum *b*, which is the water drum and mud-drum, is much shorter than the steam drum, and its top is closed by a tube-sheet *g*. At the bottom of the mud-drum, a blow-off pipe connection is made at *h* for the removal of mud and sediment. The arrangement of the manholes *i* in both the upper and lower drums permits entering the boiler at its highest and lowest points for inspection, for repairing of the tubes, and for cleaning purposes, as required in the removal of scale from the drums and boiler tubes.

The feedwater enters the steam drum *a* through a pipe *j* located at the back of the boiler, farthest from the furnace, and flows directly down through the rear tubes, called *downcomers*, to the water drum. The circulation is continued up the *risers*, or tubes, in front of the baffle wall *d*. A baffle plate is arranged

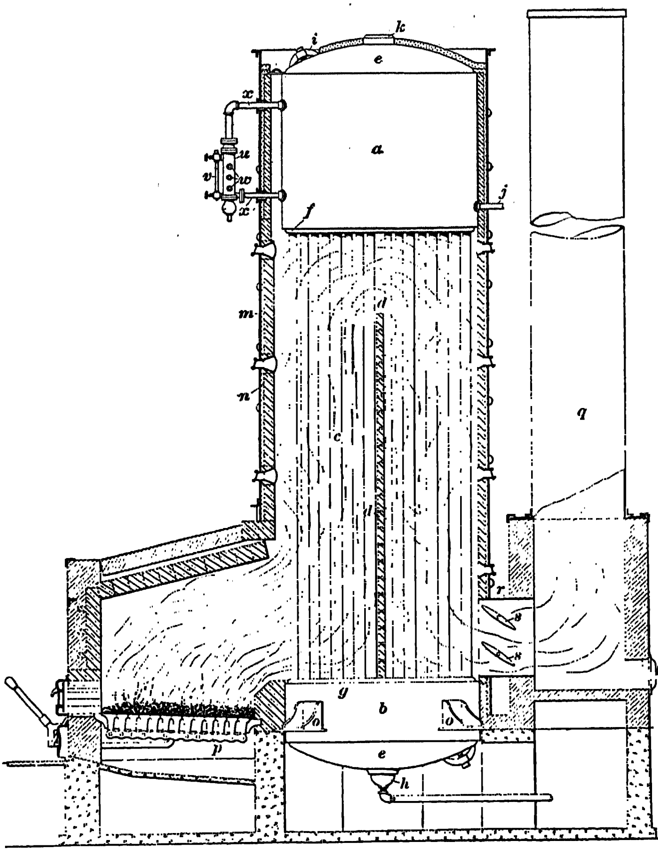


FIG. 28

on a level with the water-line in the steam drum *a*, directly over the risers. By it the water that rises with the circulation is deflected to the section above the downcomers, and thus particles of water are prevented from escaping with the steam that passes out the main steam outlet *k*.

52. The brick setting around the boiler in Fig. 28 is independent of the boiler installation. By this arrangement, the boiler is free to expand and contract without affecting the walls of the setting. The brick wall is surrounded by a steel jacket *m*, and non-conducting material *n*, such as asbestos or magnesia, is placed between the jacket *m* and the brick wall. The boiler is supported by brackets *o* that are riveted to the mud-drum and that rest on a foundation placed under the boiler. Incorporated with the setting are the furnace and grates *p*, so arranged outside of the boiler that the heat and flames have a long travel around the boiler tubes. The flow of the heated gases is produced by the draft of the chimney *q*. They flow around the first bank of tubes in front of the baffle *d*, over the baffle, down about the downcomer tubes, through the breeching *r*, and to the stack. A double swinging damper *s* is installed in the breeching between the stack and the boiler setting, to control the draft or flow of gases. A clean-out door *t* is placed back of the stack, in the setting, so that entrance is made for cleaning, inspection, and repairs to the stack connection. Boiler accessories, such as the water column *u*, with the gauge glass *v* and the gauge-cocks *w*, are attached to the steam drum *a* by the piping *x*. The upper pipe *x* is in communication with the steam space above the highest water-line and the lower is attached below the water level.

53. Cahall Boiler.—The Cahall boiler, shown in Fig. 29, consists of a cylindrical mud-drum *a* and steam drum *b*, which are connected by nearly vertical tubes *c* that form a tube nest having an open space in the center in the form of an inverted cone. In this space are installed deflecting plates *d*, or baffles. The furnace *e* is placed to one side of the boiler, and the gases of combustion surround the tubes, being deflected by the baffles *d* to a sweep nearly at right angles to the tubes. They finally pass out through a central passage in the steam drum to the smokestack. The steam becomes slightly superheated in this steam drum, through coming in contact with the surface of the central passage, which is kept at a fairly high temperature by the escaping gases. The steam drum and mud-drum are connected by an external circulating pipe *f* that enters the steam drum

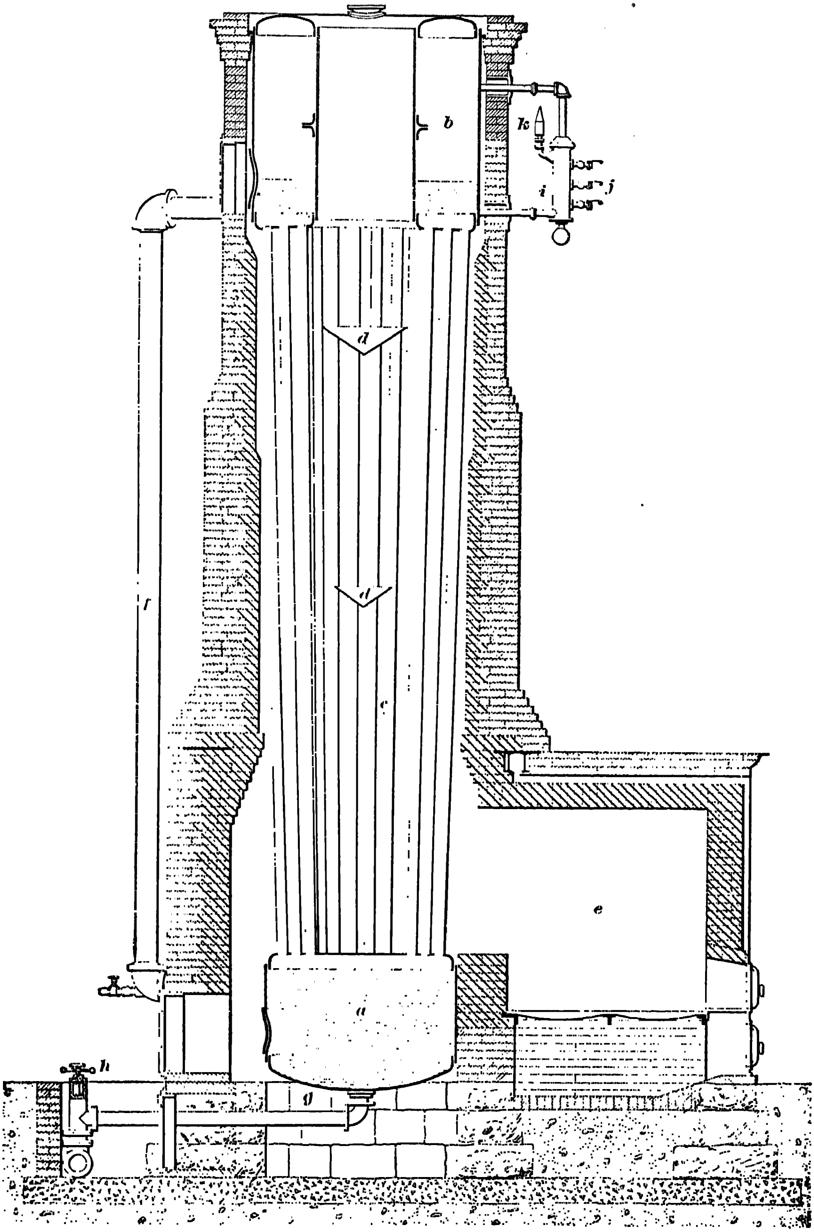


FIG. 29

some distance below the water-line. The feedwater enters the mud-drum and, becoming highly heated, rises through the vertical tubes to the steam drum, where the steam bubbles are liberated.

Some of the water in the lower part of the steam drum flows continually into the circulating pipe, and since this pipe is not exposed to the heat of the fire, the density of the water in it is much greater than the density of the water in the vertical boiler tubes. In consequence, the water is continually flowing downwards and a rapid circulation is promoted. The blow-off pipe *g* is connected to the bottom of the mud-drum, and the blow-off valve *h* is arranged on the outside of the boiler setting. The water column *i*, the gauge-cocks *j*, and the water glass are attached to the drum *b* for determining the water level. A whistle *k* is incorporated with the water column, its purpose being to give an alarm when the water level falls too low in the boiler.

MARINE BOILERS

CLASSIFICATION

54. Steam boilers for marine service are made in a great variety of forms, but there are at least four well-defined types, as follows: Scotch, locomotive, tubular, and water-tube boilers. Each branch of marine service demands a boiler adapted particularly to its requirements. For example, the Scotch boiler is used in freighters and large, slow-moving passenger steamships; the locomotive and tubular types are used in small vessels; and the water-tube types are mainly used in high-speed passenger, freight, and war vessels.

FIRE-TUBE MARINE BOILERS

55. Scotch Boilers.—The Scotch boiler is distinctively a marine boiler. It is of the fire-tube type and is internally fired, the number of internal furnaces varying from one to four,

according to the size of the boiler; but three is a very usual number. The diameter of the furnace ranges from 24 to 48 inches. Boilers under 9 feet in diameter have one furnace; those from 9 to 13½ feet in diameter have two; those from 13½ to 15 feet in diameter have three; and those beyond 15 feet in diameter have four. Large furnaces are preferable as they permit a greater inclination of the grates, thus assisting in the efficient combustion of the fuel and producing better economy. The thickness of the shell plates of the largest Scotch boilers is 1½ inches.

The simplest Scotch boiler is of the single-ended type, having furnaces and tubes at one end only, and fired at only one end. This type of boiler is made in sizes up to 18 feet in diameter and 12 feet in length. In the early form, the furnaces opened into one common combustion chamber, which made it difficult to operate the boiler economically. In the present type, each furnace and its combustion chamber are independent of the other furnaces and their combustion chambers, with water surrounding each section.

56. Single-Ended Scotch Boiler.—An end view of a single-ended Scotch boiler is shown in Fig. 30 and a longitudinal section in Fig. 31. The boiler consists of a cylindrical shell *a*, which is made in one or two sections, depending on the length of the boiler. The furnaces *b* are corrugated and of the *horse-collar* type, taking this name from the shape of the collar, or flange connection, by which the furnace is riveted to the rear tube plate *c*. Circular collars or flanges may be used, but the advantage of the horse-collar type is that the furnace can be removed through the circular opening in the front end in case repairs are required. Each corrugated furnace opens into a combustion chamber *d*, and the adjoining combustion chambers are stayed together by screw stays *e*. A nest of fire-tubes *f* extends from the front tube plate to the rear tube plate and the tube ends are expanded in the tube holes and then beaded over. The tubes *g*, of heavier metal, called *stay tubes*, are threaded and screwed into the tube plates, thus forming stays that support the tube plates.

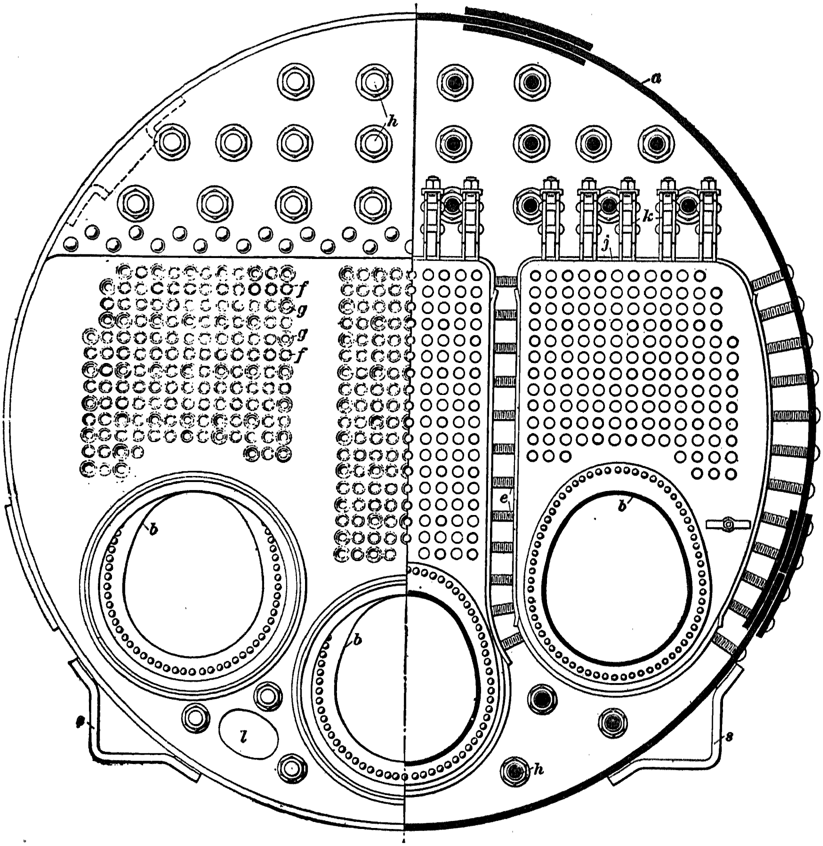


FIG. 30

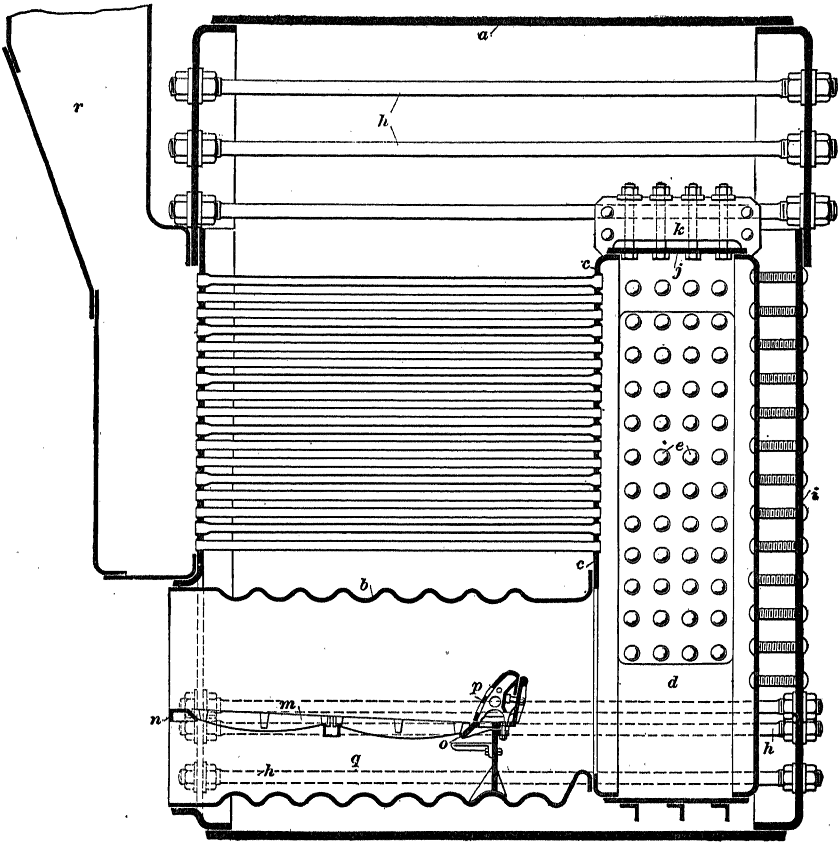


FIG. 31

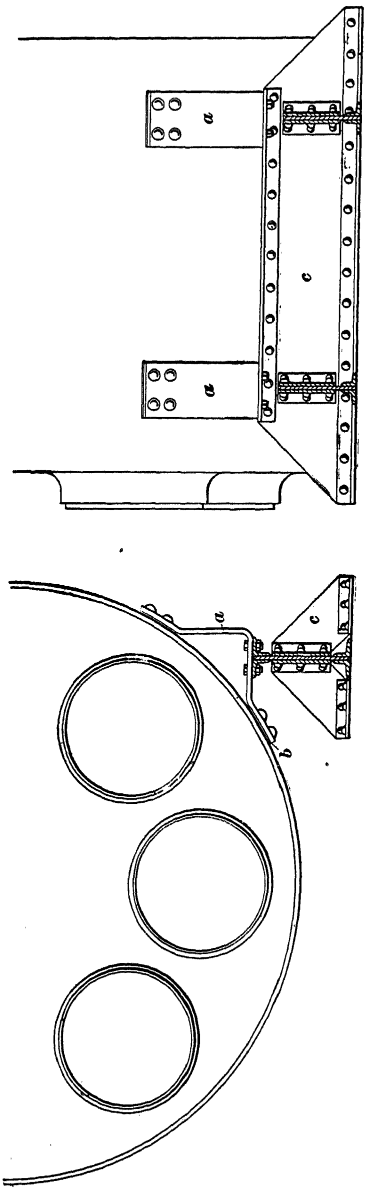


FIG. 32

57. Owing to the size of the boiler heads, they are usually made in two or three sections and riveted together. The flat sections of the rear and front heads are supported by large end-to-end stays *h*, Figs. 30 and 31, which are fitted with inside and outside nuts and washers. The sides of the outer combustion chambers are stayed to the shell plate, and the rear plates of these chambers to the back head *i*. The crown sheets *j* are supported by steel girder stays, or *crown bars*, *k*. The manholes *l* give access to the boiler for inspection and cleaning the various boiler parts. Furnace details, such as the grate bars *m* and dead plates *n*, are placed within the corrugated flues *b*. It is necessary to make the grates long in order to provide the necessary grate area. A cast-iron plate *o* supports the rear ends of the grate bars and also carries the sectional bridge wall *p*, which is made up of a series of cast-iron sections set side by side across the furnace. Slots between adjacent sections admit air from the ash-pit into the current of gases passing

over the top of the bridge wall and thus improve the combustion. Below the grates is the ash-pit *q*. The gases arising from the combustion of the coal pass into the combustion chamber *d*, where they are more thoroughly mixed with air and consumed. They then pass through the tubes to the breeching *r*. The material used in the heads is flange steel of ductile quality, and the tubes are made of the best charcoal iron or of seamless drawn steel tubes, both of which under good operating conditions give equally satisfactory results.

58. The Scotch boiler is supported by saddle plates *s*, Fig. 30, details of their construction being shown in Fig. 32. The lug *a* is of heavy steel, bent to shape and riveted to the shell of the boiler. Each lug has a calking strip *b*, made of ¼-inch plate, between it and the shell. Girders *c* are fastened to the framing of the ship, and to these the lugs *a* are bolted, provision being made at one end for freedom of movement to accommodate expansion and contraction. To promote economical operation, the bottom of the boiler is covered with *lagging*, made of asbestos or magnesia, that prevents cooling by the circulation of air along the bottom.

59. The diagrammatic views given in Fig. 33 (*a*) and (*b*) show the direction of circulation of the water in the Scotch boiler. The water directly above the tops of the furnaces *a* becomes heated and rises among the tubes *b* as well as between the nests of tubes. The cooler water above descends to take the place of the water that rises, and it travels along the shell, outside the outer nests of tubes, as well as between the rising streams between the tube nests. The directions of these various currents are indicated by the arrows.

At the bottom of the boiler, below the furnaces, as at *c*, the movement of the water is very sluggish, because the water in that space is not in contact with effective heating surface; also. there is some conflict between the rising and descending currents, to retard the circulation. As such inequality of temperature in different parts of a boiler sets up stresses in the plates and seams, devices for creating circulation of the water are sometimes used. One method is to place a steam nozzle in the

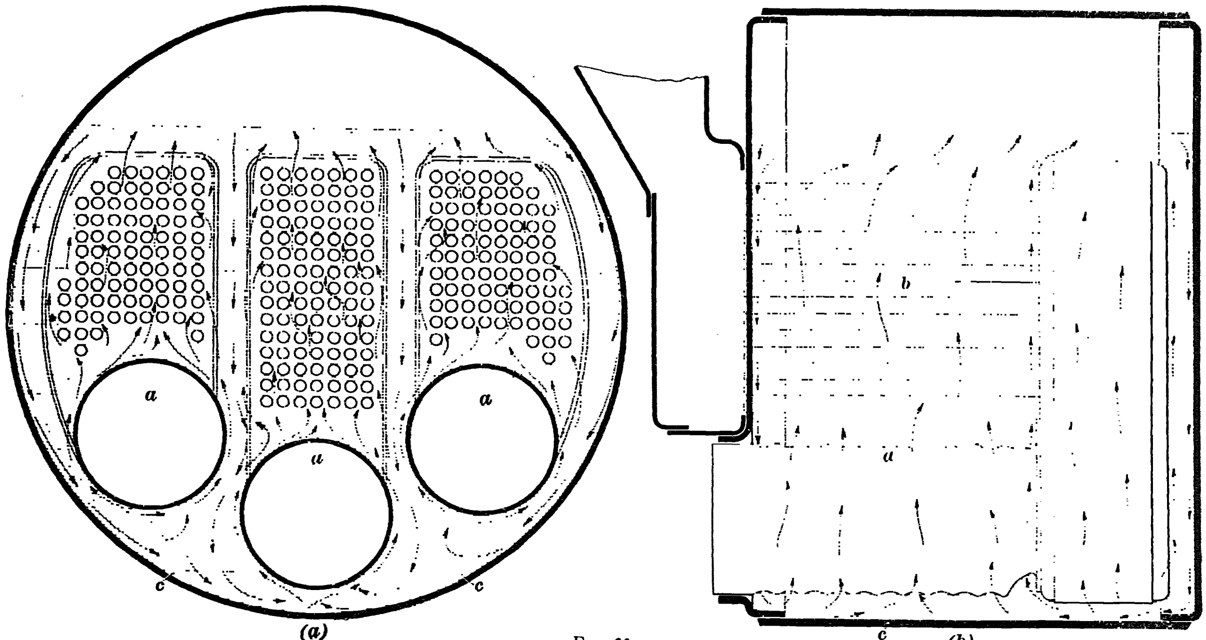


Fig. 33

water space near the bottom, and to use the escaping jet to induce a rapid circulation of the water, thus keeping all parts of the boiler at approximately the same temperature. The incoming feedwater also tends to set up a circulation of water in the boiler.

60. Double-Ended Scotch Boiler.—The double-ended Scotch boiler has furnaces at each end, and resembles two single-ended boilers placed back to back. It is lighter, cheaper, and occupies less space than two single-ended boilers. In double-ended Scotch boilers the furnace flues at each end com-

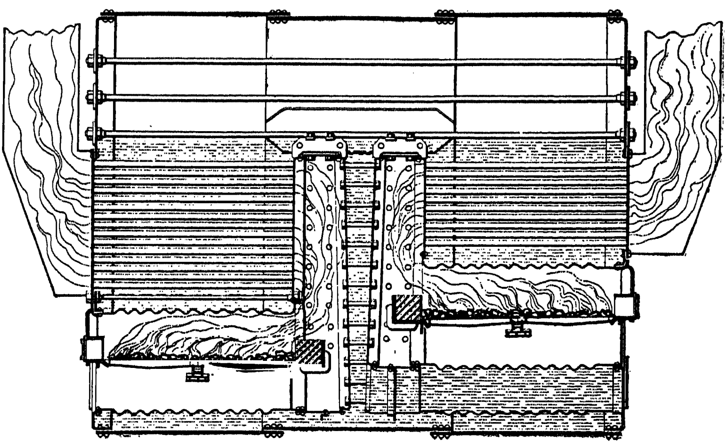


Fig. 34

municate with a centrally located combustion chamber, from which the products of combustion pass through fire-tubes, as in Fig. 34, leading to two smoke flues, one on each end. Sometimes the boiler is so arranged that each opposite pair of furnace flues opens into a common combustion chamber, as shown in Fig. 35. In such a case, each combustion chamber will have two nests of tubes, one nest connecting it with one head, the other nest with the other head. The gases from two opposite furnaces mix together in the common combustion chamber, and then pass through the two nests of tubes, one-half to one smoke flue, the other half to the other.

61. On account of the high steam pressures used in modern marine engines, the marine boiler must be carefully designed for strength. It is likewise necessary to reduce its weight and size to the lowest possible limits. The following data relating

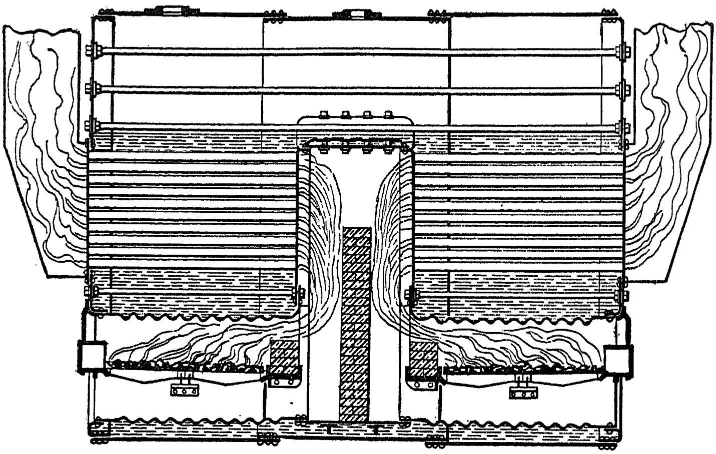


FIG. 35

to the boilers of a naval vessel will give an idea of the principal dimensions of a Scotch marine boiler made of Siemens-Martin steel.

Diameter of shell	15 ft. 2 in.
Length of shell	9 ft. 6 in.
Working pressure	135 lb. per sq. in.
Thickness of shell plates	$1\frac{5}{32}$ in.
Thickness of heads	$\frac{7}{8}$ in.
Number of furnace flues	4
Diameter of furnace flues	3 ft. 1 in.
Thickness of furnace flues	$\frac{15}{32}$ in.
Diameter of stayrods	$1\frac{15}{16}$ in.
Diameter of staybolts	$1\frac{1}{4}$ in.
Number of tubes	490
Diameter of tubes	$2\frac{1}{2}$ in.
Length of tubes	6 ft. 8 in.
Heating surface	2,500 sq. ft.
Weight without water	about 40 tons

For the sake of safety, the Scotch type of boiler must be made extremely heavy and bulky when high steam pressures

are used, and much attention is being paid to devising a type of boiler that, while retaining the good features of the Scotch type, will be lighter, smaller, and cheaper for the same power.

62. Advantages of Scotch Boiler.—The Scotch boiler is durable under rough usage, and is easy to operate and repair. The tubes are straight and standard in size, making it possible to obtain new tubes in almost any seaport. Leaky tubes can be plugged without reducing pressure on the boiler. As the tubes are straight, they are accessible for cleaning and repairing without removing boiler connections. The number of pounds of water evaporated per pound of fuel burned has proved satisfactory. It is internally fired and therefore eliminates the air leakage that arises in built-up settings. The disadvantages of this type are: excessive weight, poor circulation in the body of water below the effective heating surfaces; loss of time in starting boilers for operation; and time required to blow off and cool the boiler down for repairs.

GUNBOAT BOILERS

63. Locomotive Type for Marine Purposes.—In some gunboats and other small naval vessels, there is not sufficient room under the decks for the large Scotch boilers, and the type of boiler shown in Fig. 36, resembling the locomotive boiler, is frequently used. It is a plain cylindrical boiler with two rectangular fireboxes *a* (only one of which is shown), each connected by a nest of fire-tubes *b* to the rear boiler head. The furnaces are large, so as to leave sufficient space for combustion over the fires. Handholes *c* and *d* are located in the front head; and on top of the shell, near the rear end, is a manhole *c* that affords ready access to the interior of the boiler for inspection, cleaning, or repairs.

64. Tubular Type.—A modification of the Scotch boiler, made for the purpose of providing a boiler of small diameter that can be placed where headroom is very limited, is the gunboat boiler shown in Fig. 37. The peculiarity of this boiler is that the tubes, instead of being placed above and around the

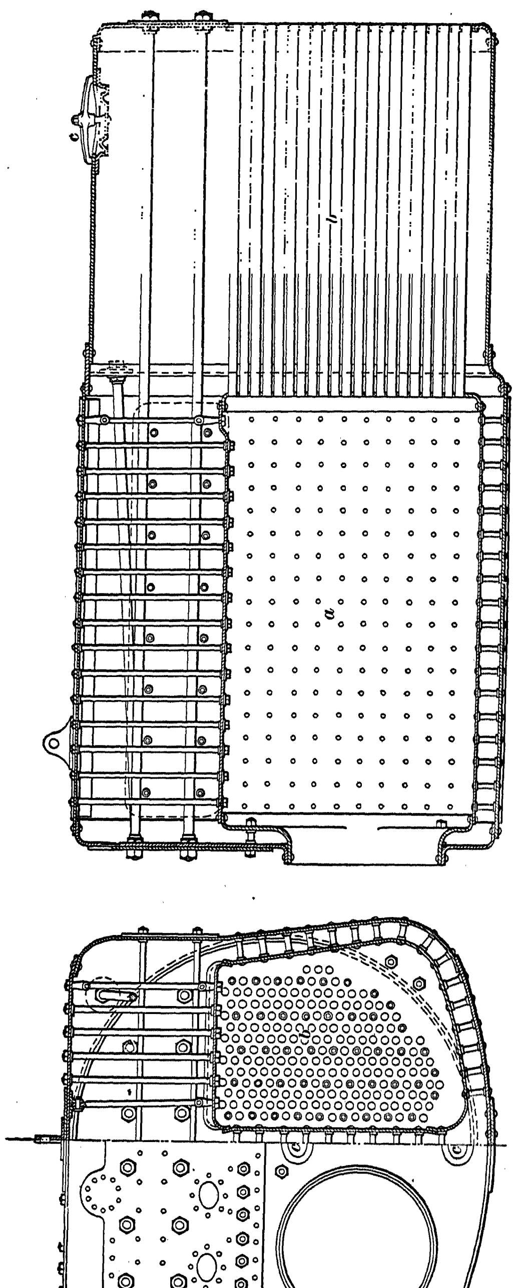


Fig. 36

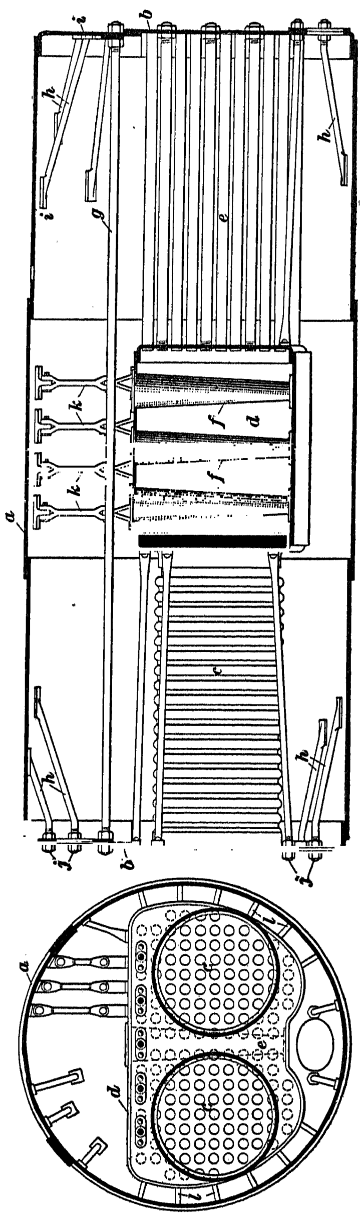


FIG. 37

furnace flues, are placed in in the rear and in line with them. By this arrangement of the parts, the boiler is greatly reduced in diameter, but its length is doubled. The reduced diameter enables the shell to be made of thinner plates. This boiler consists of a cylindrical shell *a* with flat heads *b*. The corrugated furnace flues *c* are similar to those used in the ordinary Scotch boiler, and, as usual, contain the grates.

65. The combustion chamber *d*, Fig. 37, is made twice the depth of the combustion chamber of a Scotch boiler of the same capacity, to compensate for its reduced height. The tubes *e* extend from the rear wall of the combustion chamber to the rear head of the boiler. The uptake or smokebox (not shown in the illustration) leading to the smokestack is attached to the rear head of the boiler. The combustion chamber is provided with the vertical tapering tubes *f*. These connect the upper and lower parts of the water space, promote circulation, add

considerably to the heating surface, and assist in staying and strengthening the flat top of the combustion chamber. They are made tapering to enable the flange at the lower or smaller end of the tube to be passed through the opening in the top sheet of the combustion chamber while the boiler is under construction. The tapering form, with the large end uppermost, also facilitates the release and discharge of the steam that is generated within the tubes, which are called *Galloway tubes.*

66. The heads of the boiler in Fig. 37 are braced by the tubes *e*, the furnace flues *c*, the longitudinal braces *g*, and the diagonal braces, or palm stays, *h*. The palm stays are made of round bar iron or steel forged with flat ends. In some cases, they have palms *i* at the ends, which are riveted to the shell and the head of the boiler; in other cases, they have a palm at one end only and are threaded at the other end. When they are made in this way, the palm end is riveted to the shell of the boiler and the threaded end passes through the head, with a nut on each side of the plate, as shown at *j*. The flat top of the combustion chamber is braced by the sling stays *k*. The sides and bottom of the combustion chamber are secured to the shell of the boiler by the staybolts *l*. The Clyde, or dry-back, boiler described in a preceding article is another boiler of the tubular type employed on small vessels.

WATER-TUBE MARINE BOILERS

67. Types of Water-Tube Marine Boilers.—The water-tube boilers in marine service resemble the water-tube boilers already described and possess the same advantages and disadvantages. Boilers of this type are classified as small-tube and large-tube; horizontal, vertical, and inclined; and as having straight tubes or bent tubes. The general custom is to designate marine water-tube boilers as either large-tube boilers or express boilers. Large-tube boilers, considered suitable for big ships, have tubes $1\frac{3}{4}$ inches or larger in diameter. Practically all boilers of this type have straight tubes. Express boilers are made of small tubes, from 1 to $1\frac{3}{8}$ inches in diameter.

These are closely spaced so as to obtain a high ratio of steam production to weight of boiler, which is necessary in small vessels of high speed, such as destroyers and torpedo boats. The tubes in this type may be straight or curved.

68. Features of Large-Tube and Small-Tube Boilers. Each of these types has its advantages and disadvantages, and it is a question as to which is the better. Large tubes require fewer joints for a given amount of heating surface, and they may be made thicker without decreasing materially their internal diameter. They contain a larger body of water than small tubes and so are not so liable to have all the water in them suddenly converted into steam under extreme forcing conditions, and thus leave the tubes exposed to overheating, as might occur in small tubes. Small-tube boilers generate steam more rapidly, and in case a tube is ruptured, less damage is likely to result than if a large tube should burst. Should it be necessary to plug a small tube, less heating surface will be made ineffective than in the case of the large tube.

69. Tube Arrangements.—Tubes in water-tube boilers are placed at all possible angles, from horizontal to vertical positions. The efficiency of the boiler and the ease of repairing and cleaning the tubes depend on the arrangement of the tubes. Horizontal tubes are liable to produce foaming, as the steam and water are delivered spasmodically, or in spurts, from both ends of the tubes when the boiler is forced. This condition may leave the tubes unprotected for a time and lead to overheating of the tubes. Scale and soot gather very readily on horizontal tubes, more so than on those that are vertical or are inclined at a considerable angle. Water does not circulate as freely through horizontal tubes as through inclined or vertical tubes, as the tendency of the heated water and steam to rise is resisted by the horizontal position and the small area of the tubes. As a result, the water and steam flow spasmodically.

Boilers having straight tubes properly arranged possess the advantage of being easily cleaned. Scaling tools can be passed through the tubes to remove the scale. Straight tubes can also be removed and replaced more readily than bent tubes. In

some bent-tube boilers it is necessary to remove sound tubes in order to replace a tube in one of the inner rows. Bent tubes permit a design that makes a lighter and more compact boiler than straight-tube types; hence, they are used for express boilers. Moreover, bent tubes are less liable than straight tubes to injury from expansion and contraction due to the severe operating conditions to which boilers of this type are subjected.

70. Belleville Water-Tube Boiler.—One form of large-tube boiler, known as the Belleville boiler, is shown in Fig. 38. It consists of a number of nearly horizontal tiers of water tubes *a*, screwed or expanded at each end into return bends *b*, making a series of zigzag inclined tubes, beginning at the top of the furnace door and ending at the steam drum *c*, which is located above the tubes. There is a handhole in each of the front bends or connecting boxes *b*. The mud-drum *d* stands vertically, and is located in front of the boiler and below the lowest tubes. The top of the mud-drum is connected to the bottom of the steam drum by a vertical pipe *e*. From the side of the mud-drum, a rectangular feedpipe *f* extends across the front of the boiler, joining each vertical tier of water tubes *a*. The mud-drum blow-off is at the center of the lower head.

71. The Belleville boiler is enclosed in a steel casing, as shown in Fig. 38. The fire-box is arranged below the tubes and runs their full length; the grate bars *g* slope downwards toward the rear. The products of combustion pass upwards between the tubes, thence about a superheater, and out near the top of the casing, as indicated by the arrows. Baffle plates *l* of steel or tile are fitted in the nest of tubes to deflect the hot gases, in order that the entire surface of the tubes may receive the benefit of the heat. The feedwater enters at one end of the steam drum and flows into a shallow pan *h*, then downwards through the external circulating pipe *e* to the mud-drum, and into the rectangular feedpipe *f*; thence it continues through the steam coils to the steam drum. The outlets of the water tubes in the steam drum are several inches above the bottom of the drum, so that the steam will not mingle with the comparatively cool water in the drum.

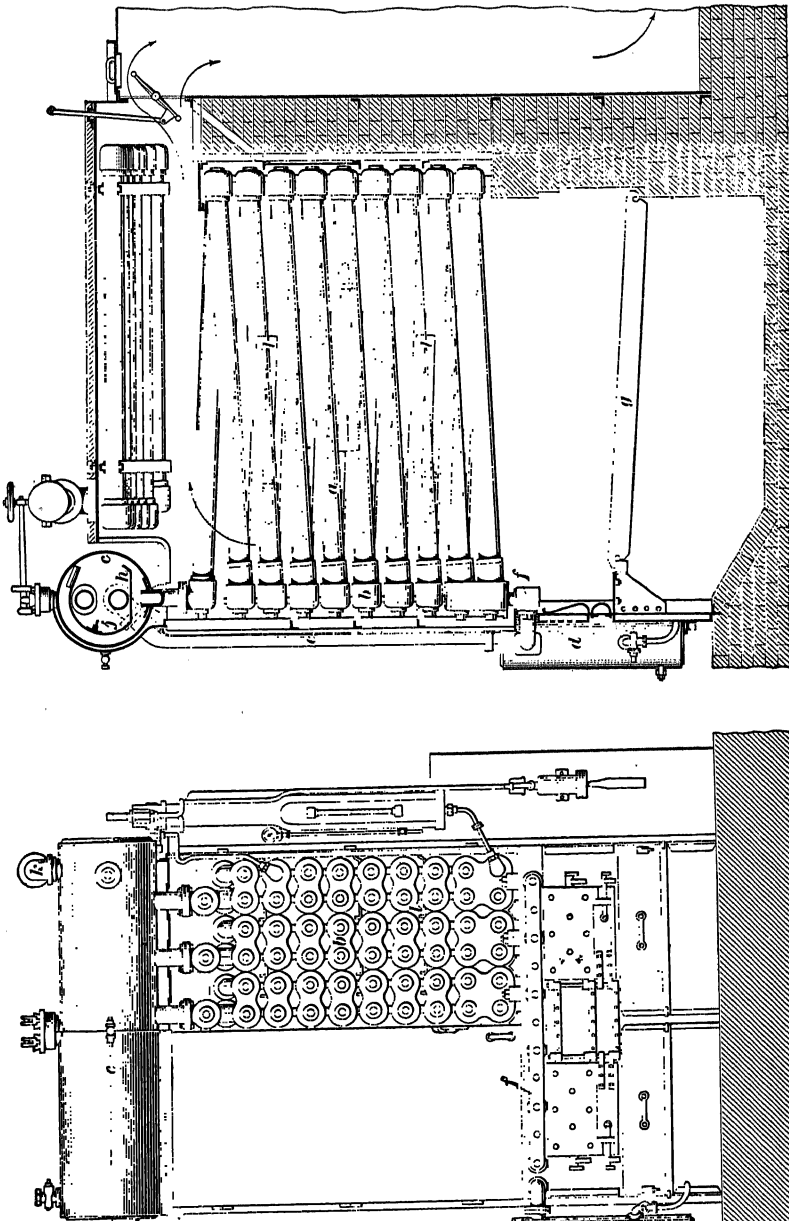


Fig. 38

72. The water passes into the mud-drum of the Belleville boiler through a non-return valve, and then to the bottom and up around a vertical baffle plate. The bottom of the drum forms a settling chamber, into which much of the sediment is deposited. The non-return valve keeps the water circulating in the same direction through the water tubes even when the ship is rolling. It also regulates the direction of flow when steam is being raised. The casing of the boiler is made of steel plates riveted together. Angle irons are used at the joints for stiffeners. The upper part of the casing is lined with magnesia and asbestos, and the lower part next to the fire with firebrick.

This kind of boiler has very little water capacity, and hence it is usually fitted with an automatic feedwater regulator. In operation, it requires very close attention. There is a strong upward flow of steam and hot water as they pass from the tubes into the steam drum. The pan *h*, Fig. 38, and its curved cover *j* serve as a deflector over the openings of the tubes to prevent the water from being carried out through the steam nozzle *k* on the top of the drum.

73. Babcock and Wilcox Marine Boiler.—The Babcock and Wilcox boiler of the mixed-tube type, built for either coal or oil burning, is one that meets the requirements of the British Admiralty, and is largely used in the United States in a variety of vessels. The dry weight of this boiler is much less than that of the Scotch boiler, averaging less than 20 pounds per square foot of heating surface as compared with 40 to 50 pounds per square foot for the Scotch boiler. The weight of water within the boiler ranges from 3 to 5 pounds per square foot of heating surface as compared with 17 to 20 in the Scotch type; hence, the space occupied by the Babcock and Wilcox marine boiler is considerably less than that occupied by the Scotch boiler of equal power.

The general features of construction, shown in Fig. 39 (*a*) and (*b*), are similar to those of the land boiler. The cross-drum *a* is placed at the front and is connected to the tube headers *b* by circulating tubes *c*. Each section of the front header *b*

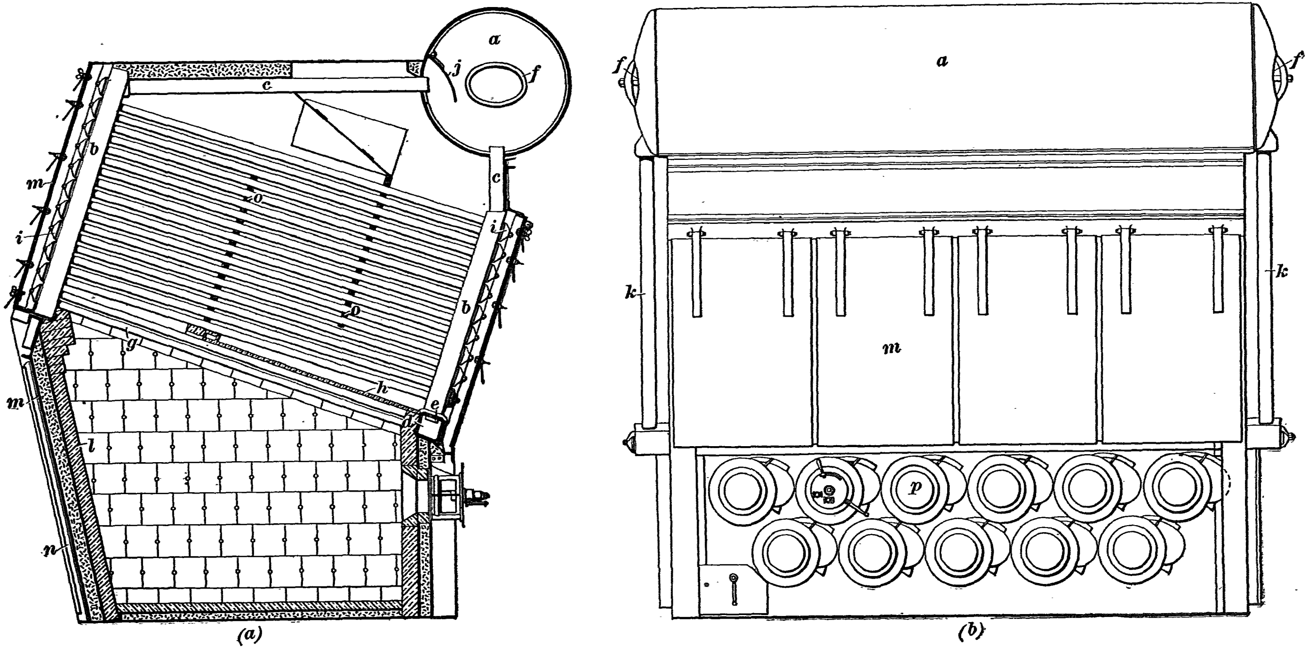


FIG. 39

is connected to the mud-drum *d*, by a short nipple *e*. At each end of the steam and water drum *a* is a manhole *f*. Directly over the furnace, in oil-burning boilers, the lower tubes *g* are inclined at an angle of 18° with the horizontal, while those above are inclined 15° with the horizontal. This difference in inclination leaves a space at the front of the boiler for the brick or tile baffle plate *h*.

74. As the tubes of the boiler in Fig. 39 are straight and accessible from each end, they are easily inspected and repaired. Handhole plates *i* are placed in the outside sheet of each tube header and opposite the tube openings. The circulation in the boiler is rapid and the steam produced is remarkably dry. Feed-water enters the drum *a*, descends through the front header, passes into the tubes, flows up through the back tube header, and through the horizontal tubes *c* into the steam and water drum *a*, striking the baffle plate *j*. The downcomers *k* also assist in promoting the circulation. These pipes connect the drum *a* and the mud-drum *d*. Mud and sediment are blown off through a blow-off valve and piping attached to the mud-drum. Handhole plates are fitted to each end of the mud-drum for cleaning and inspection purposes. The boiler furnace is encased in firebrick *l* and backed with a steel casing *m*, reinforced with angle irons *n*. The back tube header *b* is usually not covered, as boilers are usually set back to back, with a casing common to both, thus economizing room. Separate stack connections are made by installing uptakes leading from each boiler to the stack. Baffles *o* cause the gases to flow three times at right angles to the tubes. The boiler fittings, such as the steam gauge, water column, etc., are not shown. The devices *p* are oil-burning apparatus.

75. Babcock and Wilcox Box-Type Marine Boiler.—The distinctive feature in the construction of the Babcock and Wilcox box-type marine boiler, shown in Fig. 40 (*a*) and (*b*), is the arrangement of the steel headers *a* and *b*. They take the place of drums usually fitted in what is known as the **A** type of marine boiler, and are either of straight box form or of corrugated form. They run crosswise, as shown at *a*, or longitu-

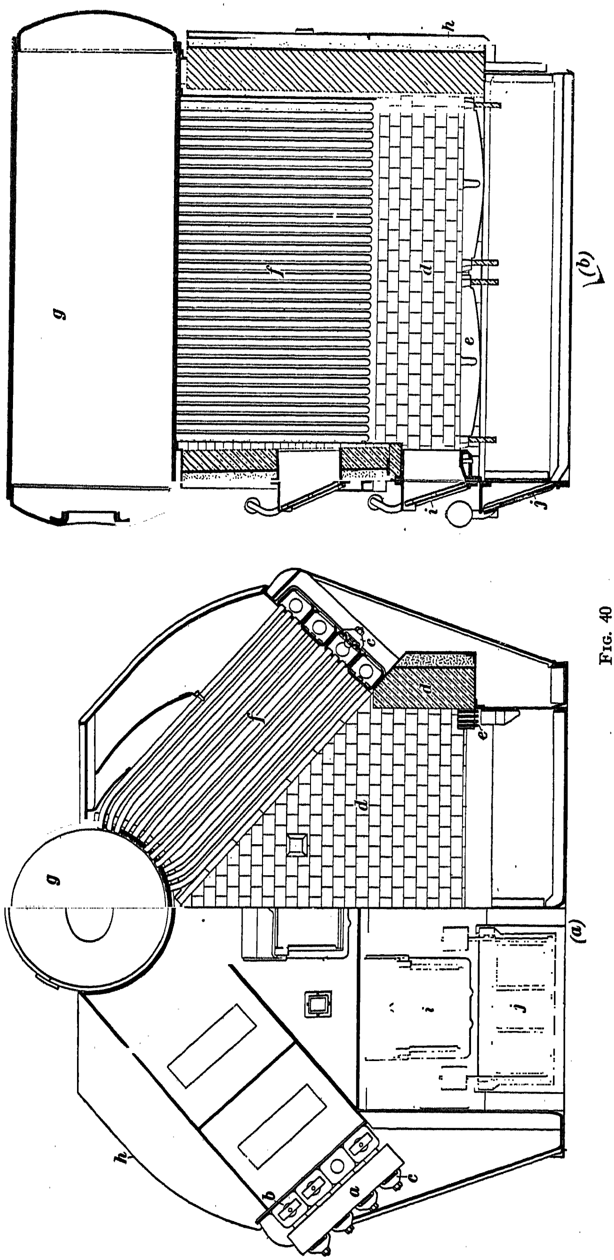
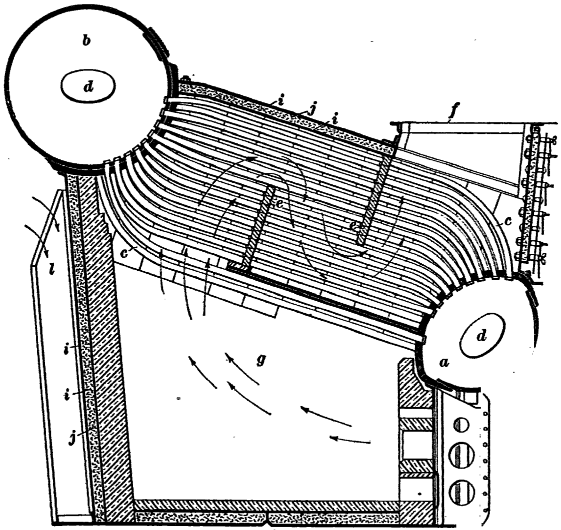


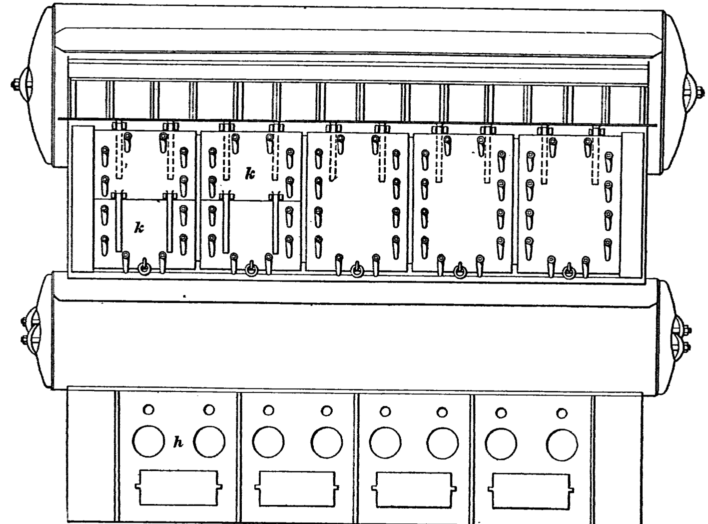
FIG. 40

dinally, as shown at *b*. Each header opposite a bank of tubes is so fitted with handhole plates *c* that examination, cleaning, and repair of the tubes may be made without interfering with other tubes. The view (*a*) is a conventional view of the boiler. The sectional drawing to the right of the vertical center line illustrates the interior arrangement of the combustion chamber and its side walls *d* and grates *e*. The tubes *f* are straight, except the end sections that join to the drum *g*, which are curved in order to have the tubes enter the drum at right angles to the contour of the shell. The view to the left of the center line indicates the details of the boiler covering, showing the steel casing *h*, fire-door *i*, and ash-pit door *j*. A lengthwise sectional elevation of the boiler is shown in view (*b*). Baffling of the gases is obtained by the use of baffle plates that are placed between the tubes and parallel to them.

76. Babcock and Wilcox Drum-Type Boiler.—In the Babcock and Wilcox cross-drum water-tube boiler, shown in Fig. 41 (*a*) and (*b*), the arrangement of the water drum *a* and steam drum *b* is such that the boiler is fired from the water-drum side. This type is an efficient design and can be operated with oil or coal as fuel. The water drum *a* is made in two sections; the lower section is semicircular and the upper part is made of heavier metal and is bent to a larger radius except at the corners, where the joint is made. This shape of the upper section permits a better arrangement and a larger number of tubes *c* in the boiler than would be possible if the section were made semicircular. At each end of the drums *a* and *b* is fitted an elliptical manhole plate *d*. The tubes *c* are bent at both ends, so that they will fit properly into the drum shells and have a good seat in the boiler plate. The bent sections have the advantage of yielding uniformly with the stresses set up by expansion and contraction. The gases are directed by baffles *e*, which are set perpendicular to the tubes, this arrangement causing the gases to make three passes around the tubes before they reach the smoke breeching *f*, which is brought forwards over the water drum *a*. The boiler setting *g* is arranged for oil burning, the oil burners being located at suitable open-



(a)



(b)

FIG. 41

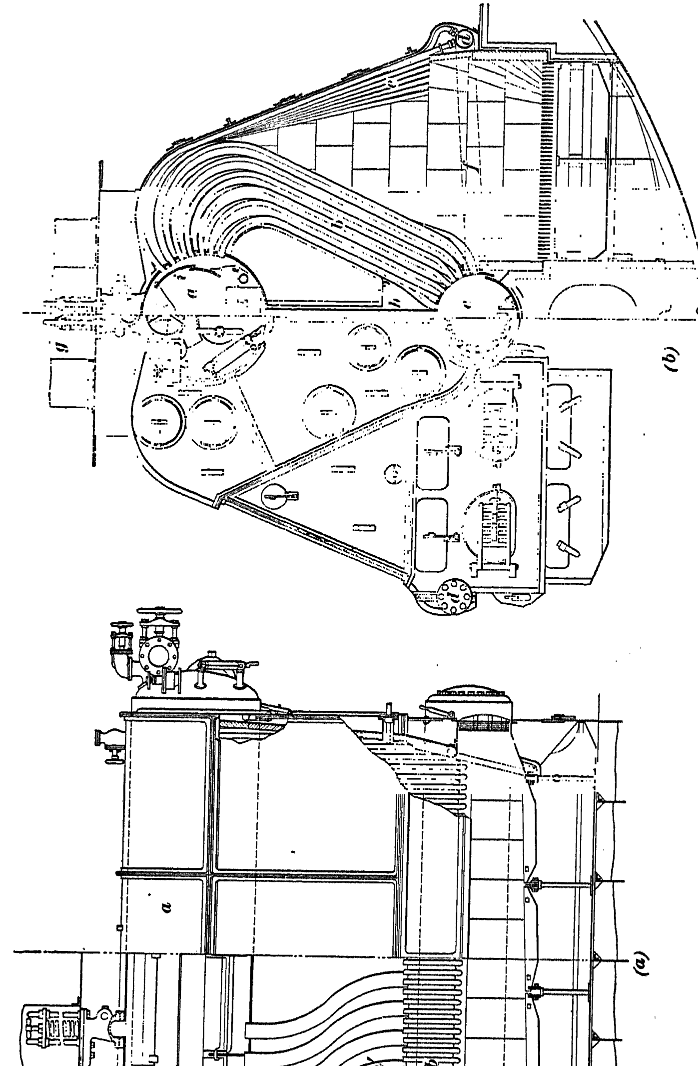


FIG. 42

ings in the boiler front, shown at *h*. The outer casing of the boiler is composed of an inner and an outer steel jacket, as shown at *i*, between which non-conducting material *j* is placed, such as asbestos, magnesia, and other mineral substances. Doors *k* are placed in the boiler casing in line with the tubes for boiler inspection and cleaning purposes. The duct *l* at the back of the boiler is for the purpose of admitting additional air to the furnace as needed for the combustion of fuel oil.

77. Thornycroft Water-Tube Boiler.—In Fig. 42 is shown the Daring type of Thornycroft boiler, a small boiler much used on boats of very high speed. It consists of a large horizontal steam drum *a* at the top, connected by a series of bent tubes *b* to a small central drum *c* located at the bottom, between the furnaces. There are also two smaller drums *d*, at the outside edges of the grates. These side drums are connected by rows of bent tubes *e* to the steam drum *a*, and by nearly horizontal pipe *f* to the lower central drum. There is a grate on each side of the central drum, and the products of combustion pass upwards between the tubes to the flue *g* at the front of the boiler. Inside the casing and near the front of the boiler are several large downcomers *h*, *h'*, joining the steam drum *a* to the lower water drum *c*. The feedwater enters the steam drum and descends through the vertical downcomer *h* to the lower drum, a portion passing to the small side drums *d*, thence up through the bent tubes *b* and *e*, where the mingled steam and water is delivered against a baffle plate *i* inside the upper drum.

The boiler setting is made of sheet-steel casing, lined with non-conducting material. Numerous doors are provided in the casing for cleaning and repairing the boiler. This type of boiler has been very highly developed and has proved very successful in torpedo-boat and torpedo-boat-destroyer service. Like all water-tube boilers, it holds very little water and is sensitive to slight changes in the condition of the fire.

78. Thornycroft-Schulz Water-Tube Boiler.—The Thornycroft-Schulz boiler, shown in Fig. 43, is a modification of the Daring boiler. It is superior to the latter in that it is more efficient in fuel consumption and evaporation. The main steam and

water drum *a* is connected to three lower drums. The bent tubes *b* connect the two outer drums *c* with the drum *a*, and the tubes are numerous, thus giving a large effective heating surface. The central drum *d* is connected to the drum *a* by bent tubes *e* and straight tubes *f* that form downcomers. Large downcomers *g* also connect the drums *a* and *c*, and assist very much in promoting rapid water and steam circulation. All of the tubes *e* and the downcomers *f* and *g* discharge into the steam drum below the water level, but only a few of the tubes *b* do this. As shown in view (*a*), most of the tubes *b* discharge directly into the steam space of the drum *a*. The tubes are formed to a large curvature and are therefore less liable to be damaged by expansion and contraction. The gases travel from the furnace in

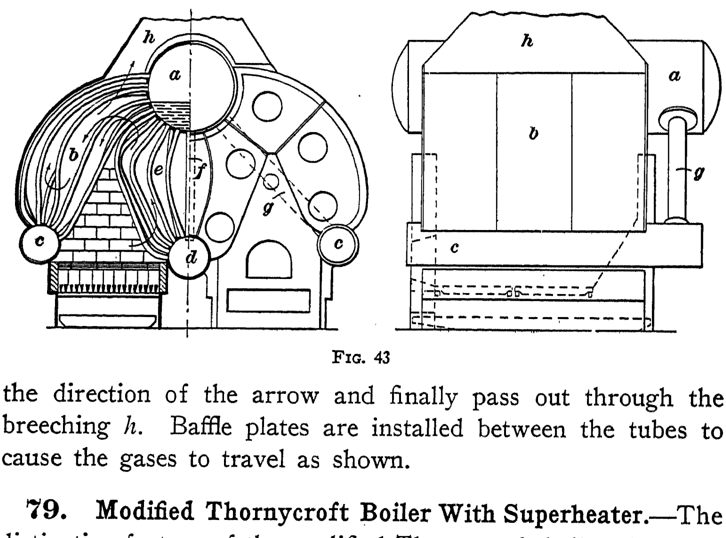


FIG. 43

the direction of the arrow and finally pass out through the breeching *h*. Baffle plates are installed between the tubes to cause the gases to travel as shown.

79. Modified Thornycroft Boiler With Superheater.—The distinctive feature of the modified Thornycroft boiler shown in Fig. 44 is the tube arrangement. View (*a*), to the left of the vertical center line, shows the interior of the boiler. The arrangement of the boiler front, superheater, and smoke breeching is illustrated to the right of the vertical center line. A rear view of the boiler is given in (*b*). The boiler is composed of an upper drum *a* and lower drums *b*, connected by the circulating tubes *c*. These tubes are straight, to the point where they

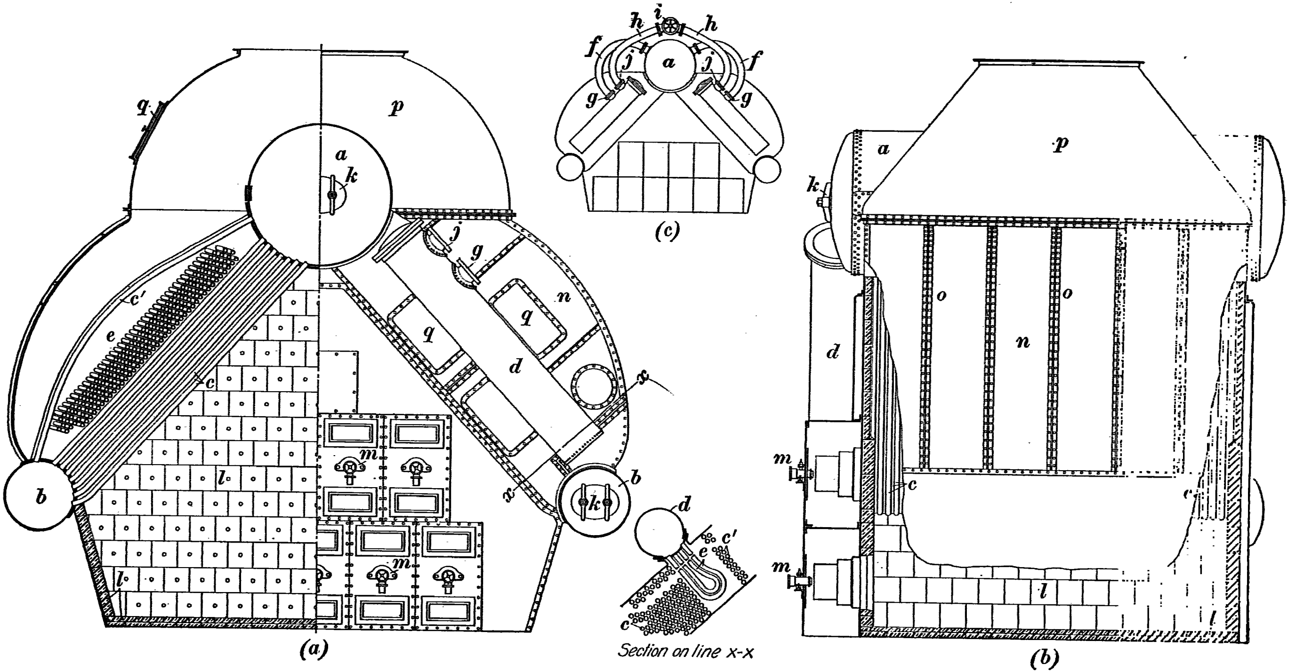


FIG. 44

join the lower drums *b*, at which point they are curved so as to fit properly into the holes in the drum. The outer rows of tubes *c'* are bent to a larger curvature and are used to baffle the gases as well as to increase the boiler heating surface. All of the tubes *c* and *c'* discharge into the water space of the upper drum.

80. The superheater drums *d*, Fig. 44, are placed outside of the boiler front, parallel with the boiler tubes. The sectional view, taken on the line *x x*, illustrates the **U** formation of the superheater coils or tubes *e*, and shows how the ends are set into the drum *d* of the superheater. The coils *e* are set directly on each tube bank, and are so connected to the steam drum *d* that the steam is drawn from the drum and circulated through the superheater coils. As the coils are directly in the path of the hot gases, the temperature of the steam is greatly increased. To convey the steam from the drum and superheater, suitable piping and pipe flanges must be installed. In view (*c*) bent pipes *f* are shown connecting the steam space of the drum *a* and the flanges *g* of the superheaters; also, bent pipes *h* connect the main steam piping *i* with the steam outlets *j* of the superheaters. This arrangement of the superheater coils and pipe connections with large bends makes the installation flexible, so that the pipes and bends give readily with the expansion and contraction stresses arising in the operation of the boiler. The superheater outlet into the main steam pipe is fitted with a safety valve. View (*a*) shows a sectional view of the superheater tubes with the drum removed, and the full front view to the right of the center line indicates the position of the superheater drum, with the pipe flanges *j* and *g* riveted thereto.

81. For the purpose of cleaning the steam and water drums, manholes *k*, Fig. 44, are provided in the heads of the drums. These openings also give access to the boiler for inspection and repairs. The furnace is built for burning fuel oil and is lined with firebrick *l*. Oil-burning equipment, such as the oil piping and the burner nozzles *m*, is arranged at the front of the boiler. The boiler casing *n* is made of two thicknesses of sheet steel, with asbestos or some other non-conductor between.

Angle-iron stiffeners *o* give additional strength and stiffness to the casing. The smoke breeching *p* is placed at the rear of the boiler. Suitable clean-out doors *q* are provided in the casing for cleaning and inspection of the boiler parts.

82. Yarrow Water-Tube Boiler.—Another form of small-tube boiler, known as the Yarrow boiler, used in torpedo-boat service, is shown in Fig. 45. It consists of a large steam drum *a*,

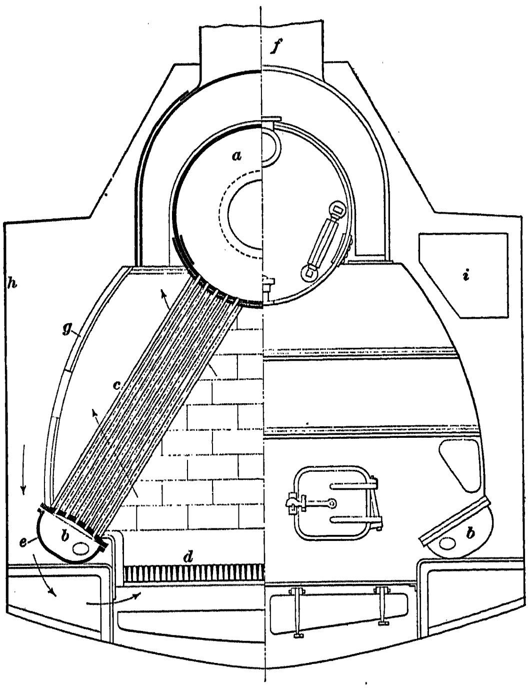


FIG. 45

with two smaller semicylindrical drums *b* below it and joined to it by inclined tubes *c*. The arrangement forms a triangle, with the grate *d* for the base. The lower drums have removable covers *e* for cleaning. The feedwater enters the steam drum below the water-line and descends through the inclined tubes most remote from the fire into the lower drum, deposits sediment, and rises through the tubes nearest the fire. The products

of combustion pass between the tubes to the smokestack *f* at the rear of the boiler. The boiler casing *g* is of iron and steel lined with non-conducting material. There is also an external casing *h* so arranged that before entering the furnace the air for supporting combustion enters the opening *i* and flows between the casings *g* and *h*. This aids materially in keeping down the temperature of the boiler room by preventing the radiation of heat.

83. Yarrow Water-Tube Boiler With Superheater.—A recent development of the Yarrow boiler adopted by the British Admiralty, is illustrated in the sectional view (*a*) and the side view (*b*), Fig. 46. It is installed with a superheater, and except for the lower drum construction, which is cylindrical in form, and the tube arrangement, it resembles the type just described. It is used for small speedy war vessels and large battleships and cruisers. The water, or generating, tubes *a* are straight, except the bottom row nearest the fire, which are bent. The tubes connect the water drums *b* and *c* to the steam and water drum *d*. As the water drums *b* and *c* are circular, the upper plate section *e* must be made heavier so that the tubes will have sufficient bearing area to insure steam-tight connections, and also to give the required strength to the tube-plate sections. The superheater drums *f* and *g* are also cylindrical and run parallel with the water drums *b* and *c*. The superheater tubes *h* are bent to a **U** shape and their ends are expanded into the superheater drums. To do this work to the best advantage, handhole plates *i* are installed opposite the superheater-tube openings, and through them the tubes are expanded. A downcomer *j* connects the drum *f* of the superheater with the steam pipe *k* inside the steam space of the boiler. Steam is drawn through the pipe *k* and the downcomer and circulates through the drum *f* and the tube sections of the superheater to the drum *g*, which is connected with the main steam stop-valve *l*. An auxiliary steam pipe *m* is also arranged in the steam space of the steam drum, to which is also fitted an auxiliary steam stop-valve *n*. The auxiliary steam feed piping and valve are used in case it is necessary to cut out the superheater for repairs.

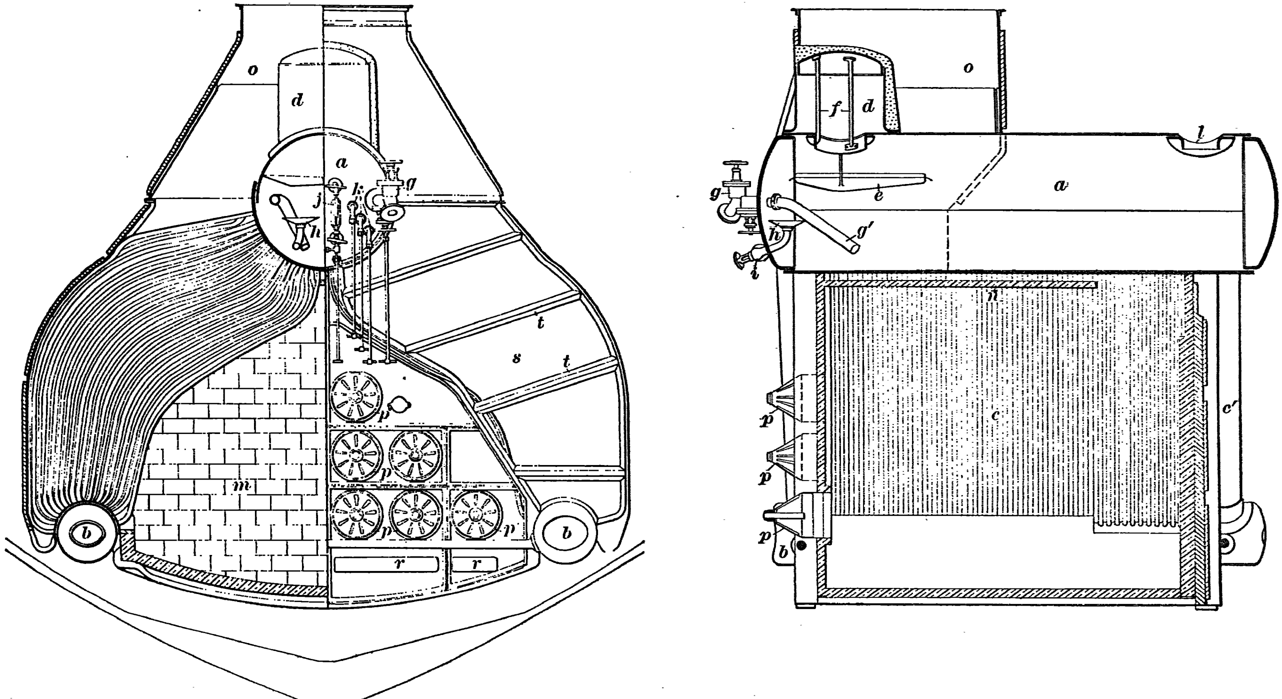
84. Feedwater enters the steam drum *d*, Fig. 46, through a perforated pipe *o*, or an auxiliary feed-pipe *p*. The arrangement of this piping is shown in the sectional view (*a*), and in view (*b*) is shown how far the perforated pipes extend into the drum. Feed check-valves are arranged in the feed piping as shown at *q* to prevent the feedwater from returning from the boiler into the feed piping. A gauge glass is placed at *r* and a scum blow-off valve at *s* with internal piping *t*. The scum blow-off is used to remove oil and other matter that collects on the surface of the water. At the bottom of the water drums is a blow-off valve *u*, connected to suitable piping, for the removal of mud and other sediment that collect in the water drums. Double safety valves *v* are connected to a flange riveted to the steam drum. One of the valves is set to blow at a slightly higher pressure than the other, so that, in case the first valve should not blow off and relieve the rising pressure within the boiler, the auxiliary valve will then blow and prevent an excess of steam pressure. Attached to the water drums and steam drum are zinc slabs arranged in trays *w* and supported by hangers that are riveted to the drums. The zinc offsets corrosion due to the galvanic action that arises in the boiler. The corroding elements attack the zinc plates instead of the boiler plates. Air and drain valves *x* are attached to the superheater drums, to relieve them of air or water of condensation that collects when the boiler is not in operation. In starting the boiler to meet sudden emergencies, these valves are opened, which allows the air and water to escape, and the steam circulates more freely in the superheating tubes.

85. The furnace of the boiler in Fig. 46 is constructed for burning fuel oil, and is lined with a special grade of firebrick that withstands very high temperatures. The baffle plates *y* cause the flame and products of combustion to circulate freely about the generating tubes and superheater before reaching the uptake or breeching *z*. The division plate *a′* separates the uptake into two parts and prevents the formation of eddies or back currents due to the meeting at this point of the gases from each side of the boiler. The funnel *b′* is directly attached to the

breeching, and where there are a number of boilers set in a battery, the breeching is made so that it receives the gases from all the boilers in the battery. This breeching connects directly with the stack. Fuel-oil burners *c'* are installed at the front of the boiler. Attached to the water drums are boiler supports *d'*, shaped to fit the contour or outline of the drum shell and made with flat bases for bolting down. The boiler is covered with a steel jacket composed of two steel plates with asbestos between, and stiffened by angle irons. The exposed parts of the drums are covered with non-conducting material, commonly called *lagging*. The bottom of the furnace is composed of firebrick laid on steel plates *e'*, called a pan. A layer of asbestos is placed between this plate and the bottom steel plate *f'*.

86. Normand Water-Tube Boiler.—The Normand boiler, shown in Fig. 47 (*a*) and (*b*), is considered one of the most efficient small-tube boilers. It is largely used in small war vessels of the speedy type by France and to some extent by the United States. The dry, or empty, weight of the boiler, as fitted for oil burning, with steam and water accessories, but not including the uptake and stack connections, is approximately 11 pounds per square foot of heating surface. The weight of water under steaming conditions is about 2 pounds per square foot of heating surface. The boiler is of the **A** type, having a main steam and water drum *a* and water drums *b* connected by generating tubes *c* and a downcomer *c'*. These tubes are small in diameter and bent so as to form an arch-shaped nest of tubes above the furnace. To the drum *a* is riveted a steam dome *d*. The steam in passing to the steam dome strikes the baffle plate *e*, which aids in preventing the very moist steam from entering the main steam outlet. The dome head is supported by the stays *f*. The feedwater enters the drum *a* through the valve connections *g* and piping *g'*.

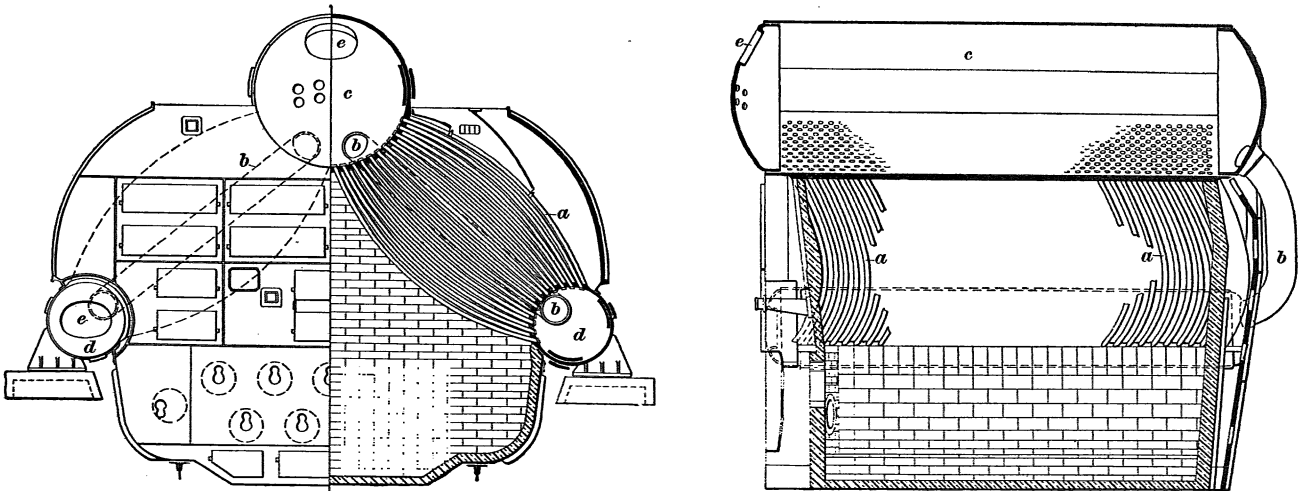
87. A scum blow-off pan *h*, Fig. 47, is located at the given water level, as indicated in view (*a*), and a blow-off valve *i* is installed for the removal of scum, grease, and oil, as required. The gauge glass *j* is attached to the steam and water drum *a* and gauge-cocks *k* are also so placed that the water level can be



(a)

FIG. 47

(b)



(a) (b)

Fig. 43

readily determined. A manhole opening *l* is formed in the shell of the drum *a* and is so shaped that the flanged section around the manhole opening adds strength to and supports the shell plate of the drum. Manholes are also installed in the water drums *b*. The furnace is lined with firebrick *m* and the boiler tubes are baffled at *n* so that the gases pass entirely around the tubes and drum before entering the uptake *o*. Oil-burning apparatus *p* is arranged conveniently at the front of the boiler furnace. Clean-out doors *r* are installed in the boiler front for the removal of soot. The casing *s* is made of two steel plates, between which asbestos or other non-conducting material is placed. Angle-iron stiffeners *t* are used to give the necessary strength to the casing.

88. White-Forster Water-Tube Boiler.—The White-Forster boiler, shown in Fig. 48 (*a*) and (*b*), is also of the small-tube type. The generating tubes, or water tubes, *a* are all 1 inch in diameter, outside, and have a thickness of .104 inch. The downcomers *b* are 4¼ inches in diameter, outside, and have a thickness of .212 inch. The generating tubes *a* are bent and connect the steam and water drum *c* with the water drums *d*. The forward drum heads are fitted with manholes *e*, thus giving access to the drums for cleaning and repairs. The tubes are curved alike, as shown in the side view (*b*), and their arrangement and curvature are such that any tube or number of tubes can be readily removed through the manhole opening *e* in the steam drum *c* without affecting adjoining tubes. The tube holes in the drum *c* are larger than those in the drums *d*, to facilitate the work of installing tubes. As the tubes are curved when viewed from either the side or the front, stresses are not likely to affect the tubes by reason of expansion or contraction. The boiler furnace and casing are similar to those previously described, but there is no baffling of the gases. The boiler shown is arranged for oil burning. This type of boiler produces rapid evaporation of water without forcing the fires.

LOCOMOTIVE BOILERS

89. Classes of Locomotive Boilers.—The locomotive type of boiler is used to the exclusion of all other types in railroad work. It is made in three general forms, known as the *straight-top boiler,* the *extended wagon-top boiler,* and the *conical boiler.* Any one of these forms may have either a Belpaire firebox or a wide firebox.

90. Straight-Top Boiler With Wide Firebox.—In Fig. 49 is shown the straight-top locomotive boiler with wide firebox. The general construction is similar to the other types of locomotive boilers. The shell courses *a* are of uniform diameter, and as the courses are straight instead of tapering, the boiler is designated as a straight-top boiler. The firebox is known as the wide firebox on account of its shape, being shallow and extending beyond the driving wheels of the locomotive at the sides. A boiler of this shape, designed for burning anthracite, is known as the *Wooten firebox.* In some of the designs the roof sheet *b* slopes toward the back head *c* instead of being straight, as illustrated. The bottom of the shell course adjoining the firebox is also made tapering in some designs, to furnish more water space around the tubes and the forward end of the firebox. The back head *c,* throat sheet *d,* and door sheet *e* are flanged so as to fit the firebox side sheets properly. The door ring *f* is riveted to the flanges of the door openings in the back head and door sheet. The crown sheet *g* slopes toward the door sheet, to which it is riveted. Crown stays support the roof and crown sheet against internal pressure and the stays *h* support the flat surfaces of the side sheets and the heads of the firebox.

91. The back head is also supported by diagonal stays *i,* Fig. 49, which are attached to T-iron braces *j* that are riveted to the back head. A number of washout holes *k* are arranged in convenient places in the outer sheets of the firebox for the purpose of cleaning the crown sheet and removing mud and other sediment from the mud-ring *l.* The projecting lugs of the mud-ring at the back-head and throat-sheet ends are used to attach

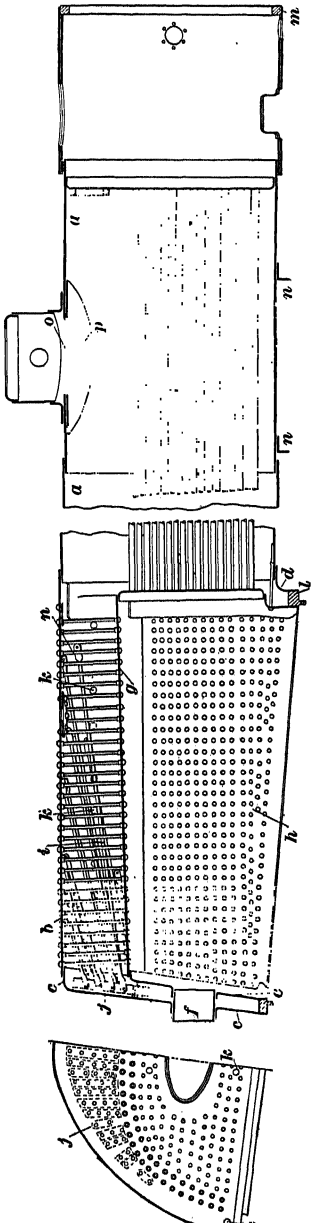


FIG. 49

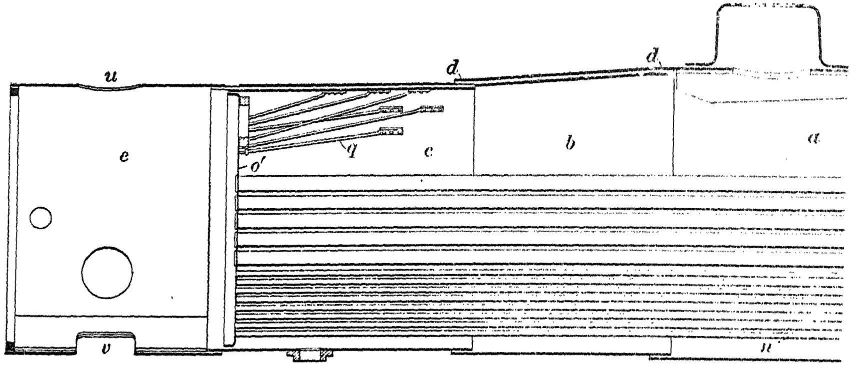
the ash-pan installed below the fire-box. A ring *m* at the front of the smokebox permits the attaching of the smokebox front. Gusset plates *n* are riveted to the bottom of the shell courses and used for bolting the boiler to the engine frame. The shell-plate opening *o* for the dome is reinforced by a steel-plate ring *p*, called a *dome stiffening ring*, which ring adds strength to the plate around the dome opening.

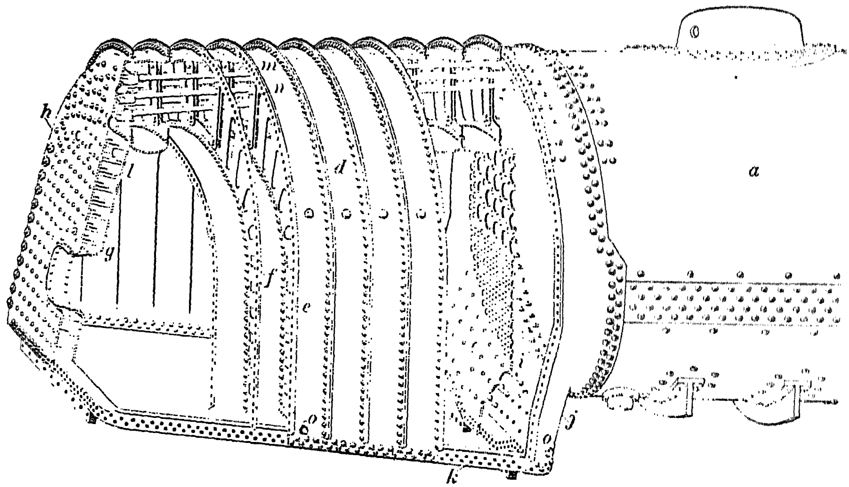
92. Extended Wagon-Top Boiler With Belpaire Firebox. The extended wagon-top boiler with a Belpaire firebox is shown in Fig. 50. The barrel section of the shell is made up of three sections *a*, *b*, and *c*, called *courses*, riveted together by circumferential seams *d*. The course *a*, next to the firebox, is cylindrical and is called the *dome course*. The course *b* is the *taper course*, as it is tapered so as to join the cylindrical courses *a* and *c*, which are not of the same diameter. The course *c* is commonly called the *first course*, and to the front of it is riveted the smokebox *e*. In the earlier designs, the taper course *b* extended to the firebox, and from this arrangement it was known as a wagon-top

boiler, its name being taken from the shape of the tapering top section of the course *b*. The dome in the wagon-top type was placed on the top of the firebox and required special staying. The use of the cylindrical shell *a* next to the firebox, and the setting of the taper course forward, permitted the dome to be installed on the cylindrical shell, in front of the firebox. To distinguish this arrangement of shell courses from the earlier wagon-top boilers, the type illustrated is called the extended wagon-top boiler.

93. The firebox shown in Fig. 50 is known as the Belpaire firebox. The top sheet *f*, called the *roof sheet,* and the crown sheet *f′* are made flat, or with a slight curvature. The corners *g* of the crown sheet are bent to a slight radius, and sufficient material is allowed to form a lap joint, connecting the inside firebox side sheets *h* and the crown sheet. The roof-sheet corners *g′* are rolled to a larger radius and with depending sides that butt against the outer side sheets *h′*. By the use of cover-plates *i* and *i′*, commonly called *welt straps* or *butt straps,* the joint is riveted, forming a butt joint. The inner and outer sheets of the firebox run practically parallel and their flat surfaces are supported by straight stays *j*. Transverse stays or cross-stays *j′* support the flat surfaces between the roof-sheet corners and the outer side sheets.

94. The door end of the inside firebox, Fig. 50, is closed with a flanged head *k,* called a *door sheet,* that has a flanged opening turned near the center of the head for the door connection. The outside head *k′*, called the back head, is riveted to the outside side sheets. It is also flanged for the door opening so that when the two flanged heads are relatively arranged and riveted to the firebox, the flanges of the back head and the door sheet overlap to form a riveted connection called the door ring. The flat surface of the back head above the plane of the crown sheet is braced by **T** irons *l*. A flanged sheet *m,* called the throat sheet, connects the outside sheets of the firebox to the bottom of the shell *a*. The throat sheet is made in different shapes, depending on the form of the firebox. Usually it is flanged so that it fits around approximately one-half of the shell. For the





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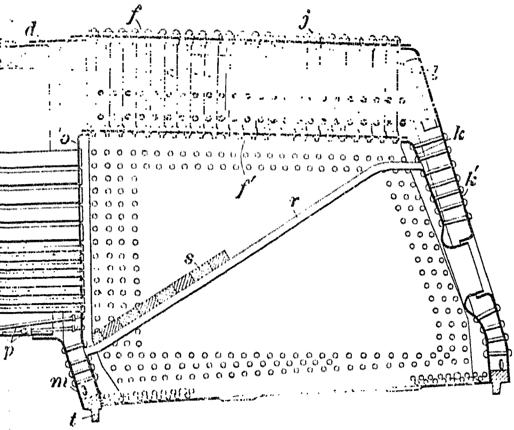
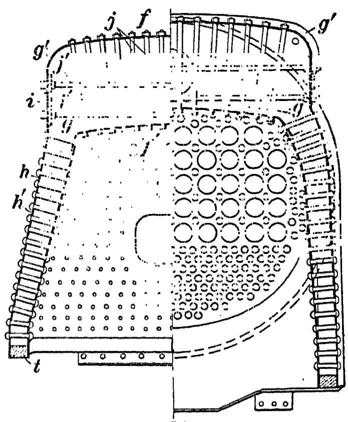
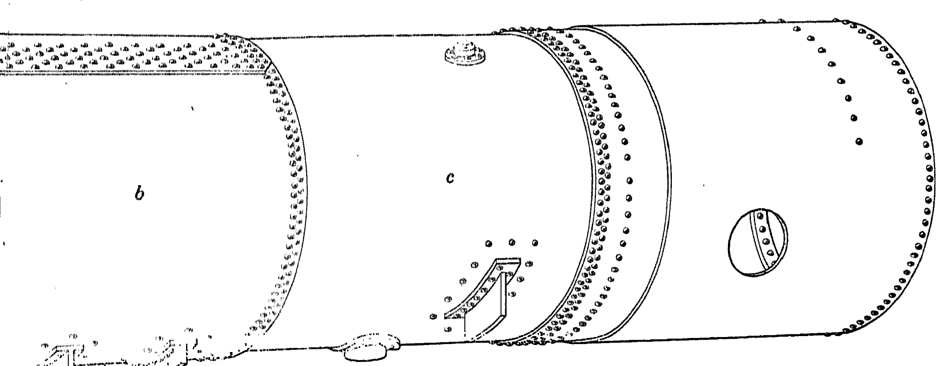




(b)

50



51

installation of the tubes *n* and flues *n′*, a firebox tube-sheet *o* and a front tube-sheet *o′* are drilled for the required number and diameter of tubes and stays. The tubes and flues extend from the firebox tube-sheet to the front tube-sheet. The tubes are 2 or 2¼ inches in diameter and the flues from 5⅜ to 5½ inches in diameter. The superheater tubes are placed inside the flues and extend from the smokebox to the firebox tube-sheet. The flat section of the firebox tube-sheet *o* is supported by stays *p* called *belly,* or *throat, stays* and the segment of the front tube-sheet *o′* above the tubes is supported by gusset stays or diagonal braces *q*.

95. In the firebox, Fig. 50, bent tubes *r*, called *arch tubes,* extend from the firebox tube-sheet to the back head. The ends of the tubes terminate in the water space so that water will circulate freely in the tubes. The tubes form a support for a firebrick arch *s* that causes the fuel gases to mix with the air more thoroughly, thus inducing a more complete combustion of the gases before they strike the tubes. It also prevents cold-air blasts, which enter through the fire-door during the period of firing, from striking directly into the boiler tubes, and thus reduces the stresses that otherwise would arise from the contraction of the boiler plates. The bottom of the firebox is closed with a wrought-iron ring *t*, called the mud-ring.

96. The gases of combustion pass directly from the furnace, Fig. 50, through the tubes and flues to the smokebox *e*, and out of the stack opening *u*. In locomotives, a strong draft is produced by allowing the exhaust steam from the engine to discharge through the smokestack. The exhaust nozzle is placed below the stack entering through the opening *v*. The escaping steam from the nozzle carries with it the air and gases in the smokebox, drawing the gases from the furnace and thus increasing the draft in the furnace and tubes.

97. Conical Boiler With Jacobs-Shupert Firebox.—The conical boiler, Fig. 51, is of similar construction to those already described. It is made up of a cylindrical course *a*, of uniform diameter, attached next to the firebox. A taper course *b* having a uniform taper is employed to connect the shell course *a* with

the first shell course *c*. From this arrangement of the shell courses, the term conical boiler has been given to designate the boiler.

The Jacobs-Shupert firebox shown in the illustration is a patented sectional firebox having the inner and outer sides and top made up of a series of bent channel shapes *d* with depending flanges. Between the channels and riveted thereto are stay sheets *e*. By the use of this construction, no additional staying of the side sheets is required. To permit circulation of the steam and water between the channels, openings *f* are cut in the stay sheets *e*. The door sheet *g*, back head *h*, tube-sheet *i*, and throat sheet *j* are flanged so as to fit the upright flanges of the channels, to which they are riveted, as shown. The bottom edges of these sheets are straight and are riveted to the mud-ring *k*. The back head and door sheet are stayed together with the screw stays *l*, and the upper section of the back head, which is a flat plate, is supported by the diagonal stays *m*. The stay plates *e* are cut out so as to allow the diagonal stays to extend from the roof of the firebox to the back head. Sling stays *n* are used to stay the sections of the channel plate, left weakened by the removal of the solid plate sections of the sheets. Wash-out plugs *o* are installed above the mud-ring and in the outside channel sections in line with the crown sheet of the inside fire-box plates.

98. The tubes of locomotive boilers range from 6 to 22 feet in length, and may be made of steel or iron. The tubes of stationary boilers of this type are usually 3 to 3½ inches in diameter. The tubes of stationary locomotive boilers are not spaced as closely as in locomotive boilers of the railroad type. With the smaller diameter and larger number of tubes, steam is generated more rapidly than in the stationary types, small tubes proving more efficient in breaking up the fuel gases and in conducting the heat more effectively to the large body of water in the boiler.

BOILER MOUNTINGS

SAFETY DEVICES

SAFETY VALVES

FORMS OF SAFETY VALVES

1. Purpose of Safety Valve.—A safety valve is attached to a boiler to prevent the steam pressure from rising above a certain safe limit. If steam is generated faster than it is used, it will accumulate in the boiler, causing increased pressure; and if the increase of pressure beyond a safe limit is not prevented, a rupture of the boiler or an explosion may result. It is the work of the safety valve to allow the excess of steam to escape, thus automatically reducing the pressure. To do this, the valve or valves must be of such size as to permit steam to escape at least as rapidly as it is formed in the boiler. Otherwise, the steam pressure will continue to rise, even though the safety valve is open, and will result in stresses that may lead to a rupture of some part of the boiler or to an explosion.

2. Classes of Safety Valves.—A safety valve consists of a valve disk held down on its seat by pressure applied in one of several ways and acted on underneath by the pressure of the steam in the boiler to which the safety valve is attached. As long as the downward pressure exceeds the upward pressure, the valve remains closed; but when the upward pressure becomes greater than the downward pressure, the disk is forced up off its seat, and some of the accumulated steam escapes,

thereby lowering the pressure in the boiler. When the pressure is lowered to such an extent that the upward pressure on the disk no longer exceeds the downward pressure, the valve closes. There are three ways of applying pressure to the disk to hold it to its seat: (*a*) By a dead-weight; (*b*) by a weight acting on a lever, and (*c*) by the action of a spring. According to these methods of applying the downward pressure, safety valves are divided into three classes, known as *dead-weight safety valves*, *lever safety valves*, and *spring-loaded*, or *pop*, *safety valves*, respectively. The dead-weight type is used only on boilers that carry low pressures, such as heating boilers. It consists of a valve attached to a vertical stem on which are placed a number of disk-shaped weights, the valve being held to its seat by the dead-weight of the disks. On vessels that carry high steam pressures, the lever and the pop types are used.

3. Lever Safety Valve.—A form of lever safety valve is shown, partly in section, in Fig. 1. It consists of an iron body *a* with a heavy flange *b* by which it is connected to the boiler, and a flange *c* to which is connected the pipe through which the steam escapes. In the body of the valve is fastened the beveled seat *d*, on which rests the beveled disk *e*. The disk is connected to a stem *f* that passes through the cover *g* and is formed into a yoke *h* at its upper end. The

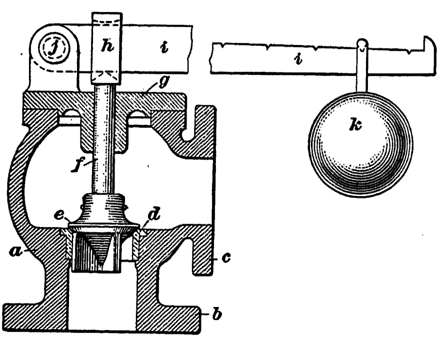


FIG. 1

lever *i* (which is broken away at the middle, so that its full length is not shown in the illustration) passes through the yoke *h* and is fulcrumed at one end on the pin *j*, held in a bracket that forms part of the cover *g*. On the other end of the lever is hung a weight *k*, consisting of a cast-iron ball, which may be moved

along the lever. The weight of the ball puts a downward pressure on the stem *f* and tends to hold the valve disk *e* to its seat. Steam from the boiler enters the space below the valve and tends to force the disk upwards, off its seat. By shifting the ball *k*, any desired pressure may be put on the stem *f* and the disk *e*, and thus the valve may be set to open when the steam pressure reaches a certain point.

4. Safety valves of the lever and dead-weight types are not looked upon with favor by engineers. There is always danger that the stem of the valve may stick in its guide and thus increase the pressure at which the valve will open; the weight on the lever may be shifted accidentally and thus change the blow-off pressure; or ignorant boiler attendants may add weights so as to obtain a higher working pressure in the boiler, regardless of the ability of the boiler to withstand the increased pressure.

The use of lever safety valves or dead-weight safety valves is not permitted under the rules of the American Society of Mechanical Engineers, commonly referred to as the *A. S. M. E. Boiler Code.*

5. Pop Safety Valves.—Lever and dead-weight safety valves have been superseded by pop safety valves. In the pop safety valve, the pressure by which the valve disk is held to its seat is obtained by a helical spring made of steel. The valve disk is made of metal that will not corrode, so as to avoid the danger of having the disk stick to its seat when in service. The disk and its seat may be flat, or both may be beveled at an angle of 45°. Pop valves of different types are made for use on stationary, marine, and locomotive boilers; also, valves for use with superheated steam differ from those for use with saturated steam. Valves for superheated steam have larger springs and in order that they may not be affected by the higher temperature, the springs are not incased in the body of the valve. Such valves may also be used to advantage with high-pressure saturated steam.

6. Pop Safety Valves for Stationary Boilers.—The pop safety valve shown in section in Fig. 2 is intended for use on

a stationary boiler generating saturated steam. The valve *a* is held to its seat *b* by the helical spring *c*, which is made of crucible steel. A stem *d* fits into a socket in the valve *a* and carries a collar *e* against which the pressure of the spring is exerted. A similar collar *f* bears on the upper end of the spring. The spring is completely enclosed by the casing *g*, which is part of the casting that forms the cover of the safety valve. The upper collar *f* is adjustable and may be forced down by turning down the screw *h*, this operation putting greater compression on the spring, forcing the valve more firmly to its seat, and thus raising the pressure at which the safety valve will open. Backing out the screw *h*, so as to allow the collar *f* to rise, decreases the compression on the spring and makes the valve open at a lower pressure. After the adjustment has been made, the locknut *i* is tightened so as to hold the screw *h* in a fixed position. The screw *h* is a sleeve that forms a guide for the upper end of the stem *d*.

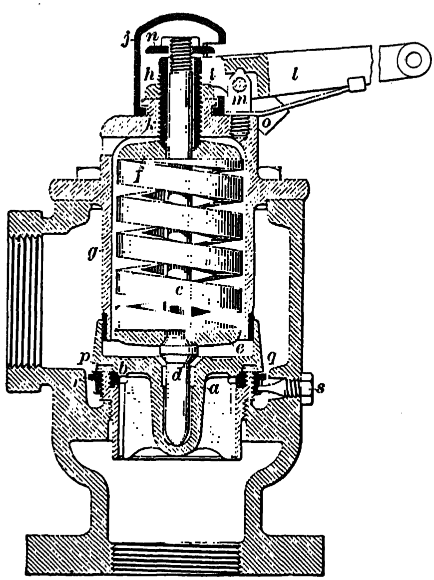


FIG. 2

7. A cap *j*, Fig. 2, is fixed permanently over the upper ends of the valve stem and the adjusting screw by having a lip forced into a groove *k* around the upper end of the valve cover. In the side of the cap is a slot just wide enough to admit the forked end of the lever *l*, which is pivoted on a pin *m*. The forked end fits around the stem *d* beneath the collar *n*, which is screwed to the upper end of the stem. By depressing

the outer end of the lever *l*, the stem *d* is raised, the pressure of the spring is removed from the valve, and the steam pressure beneath will then open the valve. This forms a method of testing the safety valve to see whether it is in working order. The pin *m* is drilled to receive the bow of a padlock *o*. No adjustment of the screw *h* can be made until the lever *l* is removed, which is done by taking out the pin *m*. The pressure at which the valve will blow off is fixed at the factory, and the valve is locked. No adjustment of the blow-off pressure can be made thereafter, except by the boiler inspector and under his supervision.

8. The upper part of the valve *a*, Fig. 2, is made with a sleeve that fits around the lower end of the casing *g*, thus forming a closed chamber for the protection of the spring. An annular space *p* is formed in the valve face, just outside the seat, and inside the lip *q*. When the steam pressure beneath is just on the point of raising the valve, the first steam to escape past the seat collects in this annular space. The area of valve surface exposed to steam pressure is thus increased, and the valve is lifted suddenly, or with a pop. It is from this sudden opening of the valve that the pop safety valve derives its name. The valve and its seat are shown beveled to an angle of 45°. Sometimes the seat is ball-ground; that is, it is ground with a curved face that is part of a spherical surface. The valve is then ground to the same curvature. The advantage of this construction is that the valve and the seat will always have a perfect bearing, even if the valve gets slightly out of alinement.

9. The extent of the reduction of pressure, or the difference between the pressure at which a safety valve opens and the pressure at which it closes, is called the *blow-down*. With the valve shown in Fig. 2, the amount of blow-down may be regulated by the adjusting ring *r*. This ring is threaded and is screwed over the seat ring, and its outer edge is notched all around. If the plug *s* is removed, a rod may be inserted, engaging with the notches, and the ring may be turned. If the ring *r* is turned up, the amount of blow-down will be

increased; that is, the drop of pressure between the opening and the closing of the valve will be made greater. If the ring is turned down, the blow-down will be decreased. A properly adjusted pop safety valve opens sharply and closes promptly, preventing undue loss of steam.

10. A pop safety valve for use on a stationary boiler that generates superheated steam is shown in Fig. 3. Its internal construction is almost exactly like that of the type just described; but the shape of the body is different, and the spring is not enclosed, so that it will not be affected by the high temperature met with in connection with superheated steam. The valve is locked, so as to prevent unauthorized changing of the blow-off pressure; also, it is sealed with a brass tag *a*, on which is stamped the number of pounds of steam that can escape through the valve in an hour, known as the *steam-relieving capacity* of the valve. A safety valve should always be attached to a superheater, and set to blow at a pressure slightly below that at which the safety valve on the boiler will blow. Then, if the engines or turbines are shut down, or the amount of steam used is suddenly decreased, the resultant rise of pressure will cause the safety valve on the superheater to open, and steam will escape by way of the superheater, thus preventing the overheating or burning of the superheater tubes.

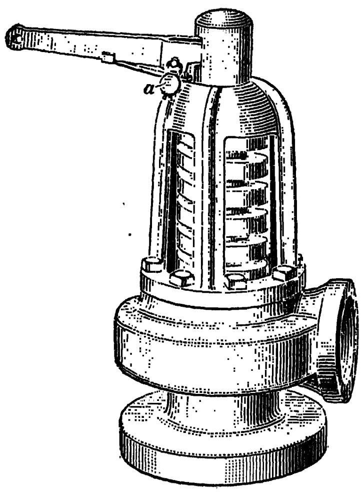


FIG. 3

11. Safety Valves for Marine Boilers.—Safety valves for marine boilers are similar to the pop valves used on stationary boilers and are made with either enclosed or exposed springs, according to the service demanded. They may be mounted

separately on the boiler or in pairs on **Y** fittings; or, two or more valves may be incorporated in one valve body, in which case the safety valve is known as a duplex, triplex, or multiplex valve.

If two or more valves are connected separately to the boiler or the steam drum, an opening must be cut for each valve. To avoid this when two valves are to be installed, the arrangement shown in Fig. 4 may be used. One opening is

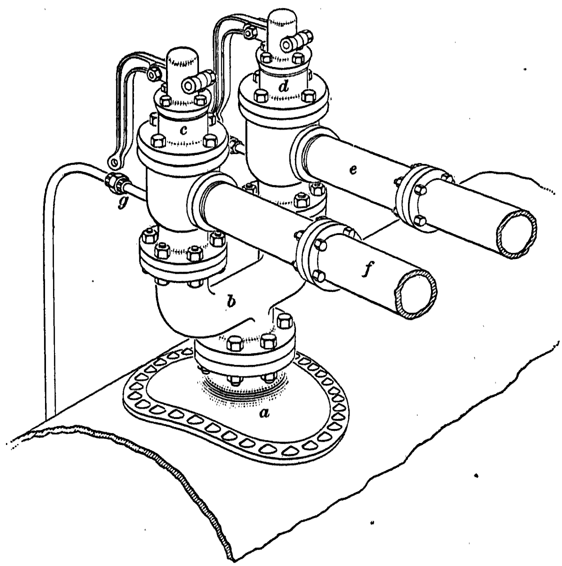


FIG. 4

cut in the shell and over it is riveted the nozzle *a*. To this nozzle is bolted the branch fitting *b* that carries the safety valves *c* and *d*. Pipes *e* and *f* lead from the valves to the main exhaust, and these pipes must be supported in such a way as to put no stress on the valves. To prevent accumulation of condensation on top of the valves, drain pipes *g* are supplied.

A duplex valve for use with superheated steam is shown in Fig. 5. The two valves *a* and *b* are installed on one body *c*.

12. Locomotive-Boiler Safety Valves.—Locomotive boilers are subjected to a service entirely different from that of

stationary and marine boilers, for they must produce steam very rapidly so as to take care of variable loads. As a result, the locomotive safety valve will frequently be in almost continual action. The feed-water in some localities is very poor, and may therefore cause scale to accumulate around the working parts, thus necessitating frequent cleaning of the safety valve. On account of the hard usage to which the valve is subjected, it must be designed to withstand the frequent blow-off action and must be of a form that readily permits repairs and cleaning operations.

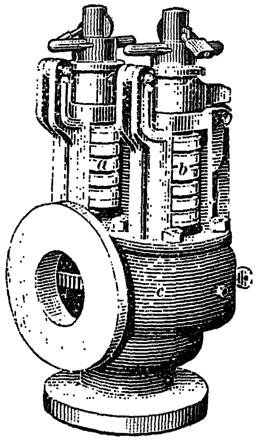


FIG. 5

A locomotive-boiler safety valve with encased spring is illustrated in Fig. 6 (*a*) and (*b*). In construction it is similar to the types of safety valves already described, except that the blow-off is at the top instead of at the side. The valve base *a*, case *b*, adjusting ring *c*, spring washers *d* and *e*, compression screw *f*, and check-nut *g* are made of bronze; and the spring *h* and the spindle *i* are made of steel. View (*b*) shows the arrangement of the steam discharge outlets *j*, which makes it possible for the steam to rise vertically, thus preventing spreading of the escaping steam, which would cloud cab windows and handicap the men operating the locomotive. Locomotive safety valves may also be fitted with mufflers to reduce the noise made by the steam while blowing off. The muffler is made of bronze, in the form of a shell, and is mounted over the body of the safety valve. To allow the escape of the steam, numerous openings are drilled in the muffler.

13. Use and Care of Safety Valves.—The safety valve must be connected directly to the boiler, steam drum, or superheater, so that there is no possible chance of cutting off communication between the boiler and the valve. The cross-

sectional area of the safety-valve nozzles or saddles and the close nipples (short sections of threaded pipe) that are used with valves having screwed flanges should not be less than that of the valve inlet. No valve of any kind should be placed between the safety valve and the boiler. A new boiler should be blown down and cleaned before the safety valve is used,

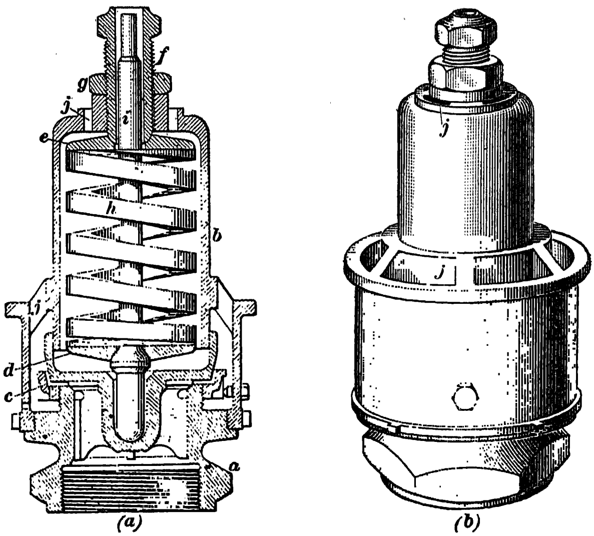


FIG. 6

otherwise, boiler-plate chips that might be left in the boiler, and other refuse, such as red lead, waste, etc., may get into the valve seat and injure it. During the hydrostatic test of the boiler, the safety valve should be gagged, instead of having the compression of the spring increased to hold the valve shut. This may be done by the use of a clamp that pulls the spring down, thus forcing the valve to hold its seat. A far better plan is to remove the valve and plug the safety-valve opening during the test.

14. Safety-Valve Rules and Regulations.—Safety valves on government marine boilers must meet the requirements fixed by the rules and regulations of the United States Board of

Supervising Inspectors. Safety valves used in stationary power plants in the United States must be made and installed in accordance with the rules of the state in which the boilers are operated. The rules of the American Society of Mechanical Engineers have been adopted by most of the states; therefore, the following data relating to the capacity, installation, and adjustment of the safety valve are taken from the A. S. M. E. Boiler Code.

Safety Valve Requirements

Each boiler having more than either 500 square feet of water-heating surface, or in which the generating capacity exceeds 2,000 pounds per hour, shall have two or more safety valves. (The method of computing the relieving capacity of the safety valves according to the A. S. M. E. requirements is given in Art. **19**.)

The safety-valve capacity for each boiler shall be such that the safety valve or valves will discharge all the steam that can be generated by the boiler without allowing the pressure to rise more than 6 per cent. above the maximum allowable working pressure, or more than 6 per cent. above the highest pressure to which any valve is set.

One or more safety valves on every boiler shall be set at or below the maximum allowable working pressure. The remaining valves may be set within a range of 3 per cent. above the maximum allowable working pressure, but the range of setting of all of the valves on a boiler shall not exceed 10 per cent. of the highest pressure to which any valve is set.

All safety valves shall be so constructed that no shocks detrimental to the valve or to the boiler are produced and so that no failure of any part can obstruct the free and full discharge of steam from the valve. Safety valves may be of the direct spring-loaded pop type, with seat and bearing surface of the disk inclined at any angle between 45° and 90°, inclusive, to the center line of the spindle. The maximum rated capacity of a safety valve shall be determined at a pressure of 3 per cent. in excess of that at which the valve is set to blow and with a blow-down of not more than 4 per cent. of the set pressure, the blow-down to be in no case less than 2 pounds.

Safety valves may be used which give any opening up to the full discharge capacity of the area of the opening of the inlet of the valve, provided the movement of the valve is such as not to induce lifting of the water in the boiler.

Dead-weight and weighted-lever safety valves shall not be used.

Each safety valve ½ inch in size and larger shall be plainly marked by the manufacturer. The marking may be stamped or cast on the casing, or stamped or cast on a plate or plates securely fastened to the casing, and shall contain the following markings:

(*a*) The name or identifying trade mark of the manufacturer.
(*b*) The pipe size of valve inlet.
(*c*) The steam pressure at which it is to blow.
(*d*) Blow-down, or difference between the opening and closing pressures.
(*e*) The weight of steam discharged in pounds per hour at a pressure 3 per cent. higher than that for which the valve is set to blow.
(*f*) A. S. M. E. Standard.

The minimum aggregate relieving capacity of all the safety valves on a boiler shall be determined on the basis of 6 pounds of steam per hour per square foot of boiler heating surface for water-tube boilers. For all other types of power boilers, the minimum allowable relieving capacity shall be determined on the basis of 5 pounds of steam per hour per square foot of boiler heating surface for boilers with maximum allowable working pressure above 100 pounds, and on the basis of 3 pounds of steam per hour per square foot of boiler heating surface for boilers with maximum allowable working pressures at or below 100 pounds per square inch.

The heating surface shall be computed for that side of the boiler surface exposed to the products of combustion, exclusive of the superheating surface. In computing the heating surface for this purpose, only the tubes, fireboxes, shells, tube-sheets, and the projected area of the headers need be considered. The minimum number and size of safety valves required shall be determined on the basis of the aggregate relieving capacity and the relieving capacity marked on the valves by the manufacturer.

If the safety-valve capacity cannot be computed, or if it is desirable to prove the computations, it may be checked in any one of the three following ways, and if found insufficient, additional capacity shall be provided:

(*a*) By making an accumulation test; that is, by shutting off all other steam discharge outlets from the boiler and forcing the fires to the maximum. The safety-valve equipment shall be sufficient to prevent an excess pressure beyond that specified in the second paragraph of these requirements.

(*b*) By measuring the maximum amount of fuel that can be burned and computing the corresponding evaporative capacity on the basis of the heating value of the fuel.

(*c*) By determining the maximum evaporative capacity by measuring the feedwater. The sum of the safety-valve capacities marked on the valves shall be equal to or greater than the maximum evaporative capacity of the boiler.

When two or more safety valves are used on a boiler, they may be mounted either separately or as twin valves made by placing individual valves on **Y** bases, or duplex, triplex, or multiplex valves having two or more valves in the same body casing. The valves shall be made of equal sizes, if possible, and in any event if not of the same size, the smaller of the two valves shall have a relieving capacity of at least 50 per cent. of that of the larger valve.

The safety valve or valves shall be connected to the boiler independent of any other steam connection, and attached as close as possible to the boiler, without any unnecessary intervening pipe or fitting. Every safety valve shall be connected so as to stand in an upright position, with spindle vertical, when possible.

The opening or connection between the boiler and the safety valve shall have at least the area of the valve inlet. No valve of any description shall be placed between the required safety valve or valves and the boiler, nor on the discharge pipe between the safety valve and the atmosphere. When a discharge pipe is used, the cross-sectional area shall not be less than the full area of the valve outlet or of the total of the areas of the valve outlets discharging thereinto, and shall be as short and straight as possible and so arranged as to avoid undue stresses on the valve or valves.

All safety-valve discharges shall be so located or piped as to be carried clear from running boards or platforms. Ample provision for gravity drain shall be made in the discharge pipe, at or near each safety valve, and where water of condensation may collect. Each valve shall have an open gravity drain through the casing below the level of the valve seat. For iron- and steel-bodied valves exceeding 2 inches in size, the drain holes shall be tapped.

If a muffler is used on a safety valve it shall have sufficient outlet area to prevent back pressure from interfering with the proper operation and discharge capacity of the valve. The muffler plates or other devices shall be so constructed as to avoid any possibility of restriction of the steam passages due to deposit.

When a boiler is fitted with two or more safety valves on one connection, this connection to the boiler shall have a cross-sectional area not less than the combined areas of inlet connections of all of the safety valves with which it connects.

Safety valves shall operate without chattering and shall be set and adjusted as follows: To close after blowing down not more than 4 per cent. of the set pressure but not less than 2 pounds in any case. For spring-loaded pop valves operating on pressures up to and including 300 pounds per square inch the blow-down shall not be less than 2 per cent. of the set pressure. To insure guaranteed capacity and satisfactory operation, the blow-down as marked upon the valve shall not be reduced.

To insure the valve being free, each safety valve on boilers with maximum allowable working pressures up to and including 200 pounds per square inch, shall have a substantial lifting device by which the valve disk may be positively lifted from its seat at least $\frac{1}{16}$ inch when there is no pressure on the boiler. For boilers with working pressures above 200 pounds per square inch, the safety-valve lifting device need not provide for lifting the valve disk $\frac{1}{16}$ inch except at such times as there is at least 75 per cent. of the full working pressure on the boiler.

The seats and disks of safety valves shall be of suitable material to resist corrosion. The seat of a safety valve shall be fastened to the body of the valve in such a way that there is no possibility of the seat lifting.

Springs used in safety valves shall not show a permanent set exceeding $\frac{1}{16}$ inch ten minutes after being released from a cold compression test closing the spring solid. The spring shall be so constructed that the valve can lift from its seat at least $\frac{1}{10}$ the diameter of the seat before the coils are closed or before there is other interference.

The spring in a safety valve shall not be used for any pressure more than 10 per cent. above or below that for which it was designed.

A safety valve over 3-inch size, used for pressures greater than 15 pounds per square inch gauge shall have a flanged inlet connection. The dimensions of flanges subjected to boiler pressures not exceeding 250 pounds per square inch shall conform to the American Extra-Heavy Standard, except that the face of the safety-valve flange and the nozzle to which it is attached may be flat and without the raised face.

Every superheater shall have one or more safety valves near the outlet. The discharge capacity of the safety valve or valves on an attached superheater may be included in determining the number and size of the safety valves for the boiler, provided there are no intervening valves between the superheater safety valve and the boiler, and provided the discharge capacity of the safety valve or valves on the boiler, as distinct from the superheater, is at least 75 per cent. of the aggregate valve capacity required.

Every safety valve used on a superheater, discharging superheated steam, shall have a steel body with a flanged inlet connection, and shall have the seat and disk of nickel composition or equivalent material, and the spring fully exposed outside of the valve casing so that it shall be protected from contact with the escaping steam.

Every boiler shall have proper outlet connections for the required safety valve or valves, independent of any other outside steam connection, the area of the opening to be at least equal to the aggregate areas of inlet connections of all of the safety valves to be attached thereto. An internal collecting pipe, splash plate, or pan may be used, provided the total area for inlet of steam thereto is not less than twice the aggregate areas of the inlet connections of the attached safety valves. The holes in such collecting pipes shall be at least $\frac{1}{4}$ inch in diameter and the least dimension in any other form of opening for inlet of steam shall be $\frac{1}{2}$ inch.

SAFETY-VALVE CALCULATIONS

15. Lever Safety-Valve Calculations.—No safety valve can open without a slight increase of pressure above that for which it is set; since, in order to lift the valve, the pressure on the under side of the valve, which may be called the internal,

or upward, force, must exceed the external, or downward, force on the valve plus the friction of the mechanism of the valve. If the internal and the external forces on the valve are equal, the valve will be balanced, and an increase of the internal force will cause it to open. A safety valve will not close until the pressure has been reduced somewhat below the pressure at which the valve opened.

The point at which a safety valve will blow off depends on the external force on the valve. To be balanced, or in equilibrium, the external load exerting a downward pressure on the valve must be equal to the internal force exerting an upward pressure on the under face of the valve. Evidently, the upward pressure is equal to the area of the valve multiplied by the pressure per unit of area.

16. Spring-loaded safety valves are always adjusted by comparison with an accurate steam gauge, and this practice is now generally employed when setting the lever safety valve. If it were possible to measure all the parts of the lever safety valve accurately, it might be finally adjusted in accordance with calculations based on such measurements. However, a slight inaccuracy of measurement of one or more of the parts may produce a considerable error, even though the figuring is correctly done. Because of this, calculations regarding the position of the weight on the lever of a lever safety valve are in practice considered as giving only an approximate, or trial, position of the weight on the lever.

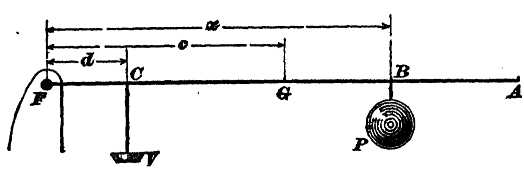


Fig. 7

17. Referring to Fig. 7, the distance from the fulcrum F to the end A of the lever is the over-all length of the lever; this is used only for finding the distance c of the center of gravity G of the lever from the fulcrum F. When the lever is straight and of the same width and thickness throughout, the

distance c is one-half the over-all length of the lever; for any other case the distance c is determined in practice by balancing the lever over a knife edge. The distance x from the fulcrum to the point of attachment B of the weight P is often called the *length of the lever*, but on account of the liability of confusing this term with the end-to-end length of the lever, it is not used here. The distance d is the distance between the fulcrum F and the center line of the valve stem C of the valve V.

Let A = area of valve, in square inches;

d = distance from center line of valve to fulcrum, in inches;

x = distance of weight from fulcrum, in inches;

p = steam pressure, in pounds per square inch;

P = weight of load or weight on lever, in pounds;

V = weight of valve and stem, in pounds;

w = weight of lever, in pounds;

c = distance from fulcrum to center of gravity of lever, in inches.

To find the pressure for which a lever safety valve is set, use the formula

$$p=\frac{Px+wc+Vd}{Ad} \qquad (1)$$

To find the weight necessary on a safety-valve lever, use the formula

$$P=\frac{pAd-(wc+Vd)}{x} \qquad (2)$$

To find at what distance from the fulcrum the weight must be put, use the formula

$$x=\frac{pAd-(wc+Vd)}{P} \qquad (3)$$

EXAMPLE 1.—At what pressure will a safety valve having a diameter of 4 inches blow off, when the weight of the valve and stem is 10 pounds; of the lever, 20 pounds; and of the ball, 120 pounds? The total length of the lever, which is straight and of uniform section, is 44 inches; the weight is 40 inches from the fulcrum, and the distance from the center line of the valve to the fulcrum is 4 inches.

SOLUTION.—The area of the valve is $A = 4^2 \times .7854$. As the lever is straight, the distance c from the fulcrum to the center of gravity is taken as one-half its length, or $\frac{44}{2}$. Apply formula **1**, and

$$P = \frac{120 \times 40 + 20 \times \frac{44}{2} + 10 \times 4}{4^2 \times .7854 \times 4} = 105 \text{ lb. per sq. in., nearly.} \quad \text{Ans.}$$

EXAMPLE 2.—With a safety valve having the dimensions given in example 1, what weight is necessary to have the valve about to blow off at a steam pressure of 100 pounds per square inch?

SOLUTION.—Apply formula **2**, and

$$W = \frac{4^2 \times .7854 \times 100 \times 4 - (20 \times \frac{44}{2} + 10 \times 4)}{40} = 113.66 \text{ lb.} \quad \text{Ans.}$$

EXAMPLE 3.—A safety valve has an area of 11 square inches; the distance from the center line of the valve to the fulcrum is 3 inches; the steam pressure, 40 pounds per square inch; the weight weighs 50 pounds; the lever is straight and parallel, 32 inches long, and weighs 15 pounds; the valve and stem weigh 6 pounds. How far from the fulcrum must the weight be placed?

SOLUTION.—Apply formula **3**, and

$$L = \frac{11 \times 40 \times 3 - (15 \times \frac{32}{2} + 6 \times 3)}{50} = 21.24 \text{ in.} \quad \text{Ans.}$$

A candidate for American marine engineer's license should thoroughly familiarize himself with the calculations pertaining to a lever safety valve, as a candidate for a marine engineer's license must be rejected by the examining inspectors if he fails to solve safety-valve problems similar to those given in the preceding examples.

18. Spring Safety-Valve Calculations.—The question often arises as to the pressure for which a safety-valve steel spring is intended. When made with 13 complete turns, the standard prescribed, the question can be answered by an application of the rule of the Board of Trade, Great Britain, governing this problem.

Rule.—*To find the steam pressure for which a spring is intended, cube the diameter, in inches, of the wire, if round, or the side of square, if square, and multiply by 8,000 for round wire and 11,000 for square wire. Divide the product by the product of the diameter of the spring, in inches, measured from center to center of the wire, and the area of the safety valve.*

Stated as a formula,

$$P=\frac{d^3 c}{D A}$$

in which P = steam pressure, in pounds per square inch;
d = diameter, or side of square, of wire, in inches;
c = 8,000 for round wire and 11,000 for square wire;
D = diameter of spring from center to center of wire;
A = area of safety valve, in square inches.

EXAMPLE.—For what pressure is a spring made of square wire measuring $\frac{1}{2}$ inch and 3 inches in diameter intended, if the valve has an area of 6 square inches?

SOLUTION.—Apply the formula, and

$$P=\frac{.5^3\times 11{,}000}{3\times 6}=76.4 \text{ lb. per sq. in.} \quad \text{Ans.}$$

Spring-loaded safety valves are finally adjusted under pressure by comparison with an accurate steam gauge, the tension of the spring being increased or diminished until the valve opens at the desired pressure. The rule given will show the approximate pressure for which the spring can be used.

19. Methods of Checking Safety-Valve Capacity.—The discharge capacity of a safety valve must be sufficient at least to take care of the maximum boiler evaporation. According to the A. S. M. E. Boiler Code, the safety-valve capacity may be determined by measuring the maximum amount of fuel that can be burned and substituting the value in the formula

$$W=\frac{.75\, C H}{1{,}100}$$

in which W = weight of steam generated per hour, in pounds;
C = total weight (or volume) of fuel burned per hour at time of maximum forcing, in pounds (or cubic feet);
H = heat of combustion of the fuel, in B. t. u. per pound (or cubic foot).

In the formula, the term .75 represents an average boiler efficiency and the term 1,100 represents the average number of

heat units required to convert a pound of feedwater into steam. The value of C is found by making a test to determine

TABLE I

HEATING VALUES OF VARIOUS FUELS

(A. S. M. E. Boiler Code)

Fuel	Heating Value	
	B. t. u. per Pound	B. t. u. per Cubic Foot
Semi-bituminous coal	14,500	
Anthracite	13,700	
Screenings	12,500	
Coke	13,500	
Wood, hard or soft, kiln-dried	7,700	
Wood, hard or soft, air-dried	6,200	
Wood shavings	6,400	
Peat, air-dried, 25 per cent. moisture	7,500	
Lignite	10,000	
Kerosene	20,000	
Petroleum, crude oil, Pennsylvania	20,700	
Petroleum, crude oil, Texas	18,500	
Natural gas		960
Blast-furnace gas		100
Producer gas		150
Water gas, uncarbureted		290

the greatest amount of fuel that can be burned per hour, and the heating value H of the fuel may be found from Table I.

20. After the value of W, the weight of steam generated per hour, has been found by the formula of the preceding article, the size of safety valve required may be determined by use of Table II. The table gives the discharge capacities of safety valves from $\frac{1}{2}$ inch to 8 inches in diameter at pressures ranging from 15 to 250 pounds per square inch, gauge.

EXAMPLE 1.—The amount of fuel burned under a boiler during the period of maximum forcing is 1,140 pounds of semi-bituminous coal per hour. If the boiler pressure, as shown by the steam gauge, is 125 pounds per square inch, find the size of safety valve required.

TABLE II

MINIMUM SIZES OF BOILER OUTLETS FOR SAFETY VALVES FROM FIRE-TUBE BOILERS FOR VARIOUS DISCHARGE CAPACITIES

Gauge Pressure	Nominal Pipe Size of Boiler Outlet for Safety Valve Connection, in Inches														
	½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6	7	8
Pounds per Square Inch	Discharge of Steam per Outlet per Hour, in Pounds														
15	49	74	131	163	245	391	486	782	1,026	1,303	1,613	2,052	2,916	3,909	5,212
25	66	99	174	218	326	523	653	1,046	1,372	1,742	2,156	2,744	3,898	5,226	6,968
50	107	161	284	354	532	851	1,064	1,703	2,235	2,839	3,513	4,470	6,352	8,517	11,356
75	148	198	393	492	738	1,181	1,475	2,361	3,099	3,935	4,870	6,198	8,805	11,805	
100	189	285	503	629	944	1,510	1,877	3,019	3,963	5,032	6,227	7,926	11,259		
125	230	346	613	767	1,149	1,836	2,299	3,677	4,826	6,128	7,583	9,652	13,711		
150	272	408	723	904	1,355	2,158	2,710	4,335	5,690	7,226	8,940	11,380			
175	313	470	835	1,040	1,561	2,497	3,121	4,993	6,553	8,320	10,298	13,106			
200	354	533	941	1,178	1,766	2,826	3,532	5,651	7,418	9,420	11,655	14,836			
225	395	593	1,052	1,315	1,972	3,154	3,944	6,310	8,280	10,514	13,013				
250	437	656	1,161	1,451	2,177	3,484	4,355	6,968	9,143	11,614	14,366				

SOLUTION.—Apply the formula of Art. **19.** From Table I, $H=14{,}500$ B. t. u.; and $C=1{,}140$ lb. Then,

$$W=\frac{.75\times 1{,}140\times 14{,}500}{1{,}100}=11{,}270 \text{ lb. per hr.}$$

On referring to Table II, it is discovered that, at a pressure of 125 lb. per sq. in., the largest size of valve, 6 in. in diameter, has a discharge capacity of 13,711 lb. per hr., but, two valves should be used on a boiler. A 4-in. valve will discharge 6,128 lb. per hr. at 125 lb. per sq. in., and two such valves will discharge 12,256 lb. per hr., which is slightly more than the value of W. Hence, two 4-in. valves will be used. Ans.

EXAMPLE 2.—A boiler carrying 250 pounds pressure burns 1,000 pounds of Pennsylvania crude oil per hour when forced to its maximum. What size of safety valve is required?

SOLUTION.—Apply the formula of Art. **19.** From Table I, $H=20{,}700$ B. t. u. for Pennsylvania crude oil; and $C=1{,}000$ lb. Then,

$$W=\frac{.75\times 1{,}000\times 20{,}700}{1{,}100}=14{,}114 \text{ lb. per hr.}$$

Table II shows that two $3\frac{1}{2}$-in. valves will furnish the necessary capacity. Ans.

FUSIBLE PLUGS

21. Purpose of Fusible Plugs.—A fusible plug is a device that is screwed into the crown sheet, tube-sheet, or water leg of a boiler to protect the boiler in case of low water. It consists of a brass or bronze shell cored out and filled with pure tin, which has a melting point a trifle higher than the temperature of the water in the boiler. As long as the plug is covered with water, it transmits the heat to the water rapidly. When the crown sheet or other boiler surface into which it is screwed is exposed directly to the heat without being covered with water, the fusible part of the plug melts quickly, and steam and water are blown through the cored opening of the plug, thus giving warning of low water. The reliability of the plug depends on the melting or fusing temperature of the tin filling at the time it should operate. The presence of relatively small amounts of impurities in the filling may cause a change in its composition and possibly render it useless. Correct methods of manufacture and the use of the best grade of filling material are the means of insuring reliable plugs.

22. Inside and Outside Fusible Plugs.—The inside type of fusible plug, shown in Fig. 8 (*a*), is screwed into the boiler plate from the water side. The hexagonal head of the plug in (*a*) makes a strong construction and enables the plug to be screwed into place. The outside type, shown in (*b*) and (*c*), is screwed into the boiler plate from the outside. Plugs are made in standard sizes from $\frac{3}{8}$ inch to $1\frac{1}{2}$ inches; they are also made with oversize and extra oversize threads, to take care of carelessly tapped holes and holes that have been retapped.

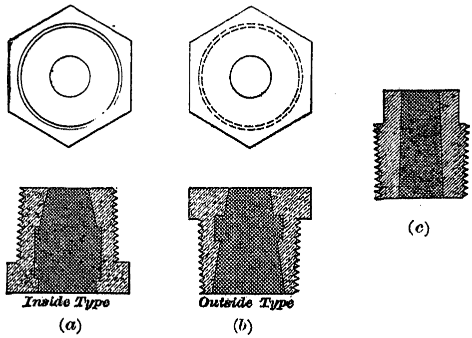


FIG. 8

A form of plug especially adapted to internally fired boilers of the locomotive type is shown in Fig. 9. The plug *a* is screwed into the crown sheet *b*, and the fusible cap *c* is laid on top of it and kept in place by the nut *d*. A very thin copper cup *e* is placed over the top of the cap *c* to protect it from any chemical action of the water. The top of the cap extends from $1\frac{1}{2}$ to 2 inches above the crown sheet, so that when it melts on account of low water, there will still be enough water left to protect the sheet from being overheated, or *burned*, as it is often termed.

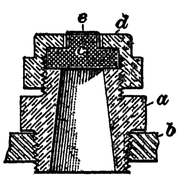


FIG. 9

23. Rules for Use of Fusible Plugs.—Although the advisability of using fusible plugs in boilers subjected to continuous overloads is questioned, the requirements of the American Society of Mechanical Engineers with regard to fusible plugs are as follows: Fusible plugs, if used, shall be filled with tin with a melting point between 400° and 500° F.

and shall be renewed once each year. The least diameter of fusible metal shall be not less than $\frac{1}{2}$ inch, except for maximum allowable working pressures of over 175 pounds per square inch, or when it is necessary to place a fusible plug in a tube, in which case the least diameter of the fusible metal shall be not less than $\frac{3}{8}$ inch.

The use of fusible plugs is not advisable in boilers that are to be operated at working pressures exceeding 225 pounds per square inch. If a fusible plug is inserted in a tube, the tube wall must be not less than .22 inch thick, or thick enough to give four threads.

24. Location of Fusible Plugs.—In horizontal return-tubular boilers, the plug is usually placed in the back head, not less than 2 inches above the top row of tubes, measuring from the top of the tube to the center of the plug. In firebox boilers of the locomotive type, the plug is screwed into the highest point of the crown sheet. In Scotch boilers, the plug is screwed into the top plate of the combustion chamber. In vertical fire-tube boilers, the plug is screwed into one of the outside tubes, and arranged so that it is at least one-third the length of the tube above the lower tube-sheet. In water-tube boilers of the Heine type, it is screwed into the shell of the steam drum, not less than 6 inches above the bottom of the drum. In general, the plug should be so located that it will be in the path of the hot gases and arranged so that it is at the highest point of the boiler, where low water would first become evident.

WATER-LEVEL INDICATORS

25. High- and Low-Water Alarms.—It is important to maintain proper water level in a boiler, so as to safeguard life and valuable equipment, as well as to insure economy in the burning of fuel. Low water may mean burned-out tubes, or crown sheets, which might lead to boiler explosions. An excessively high water level may cause priming, and flood the steam line leading to the pumps, engines, or turbines, so that damage will result to this equipment.

26. A device is often attached to the boiler to give an audible warning, usually by blowing a whistle, of a shortage or a surplus of water. Devices that indicate a shortage of water are called *low-water alarms;* those that indicate either a surplus or a shortage of water are called *high- and low-water alarms.*

In low-water alarms, the whistle may be sounded by the melting of a fusible plug, which, through the falling of the water level in a separate chamber outside of the boiler, is brought in contact with the steam. Fusible-plug alarms are cheap and easily applied; they are rather unreliable, however, because they are liable to become incrusted with scale.

The usual form of low-water alarm employs a float operating a valve leading to a steam whistle, the float being buoyed up by the water. It is like the high- and low-water alarm.

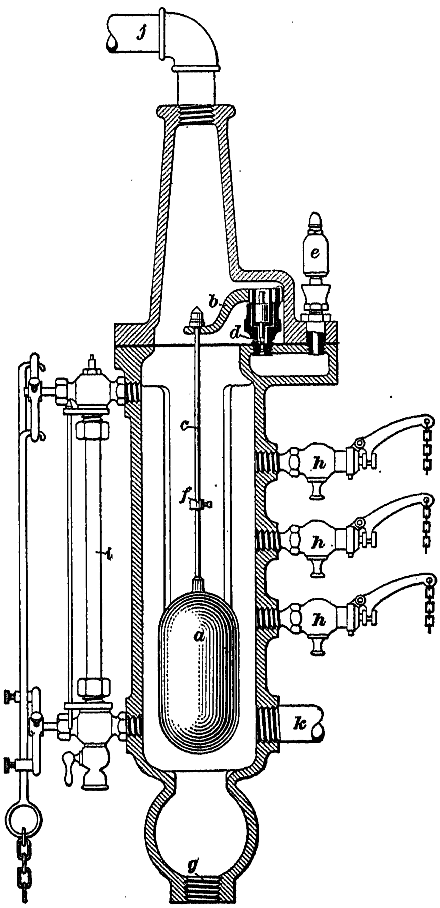


FIG. 10

27. One form of high- and low-water alarm is illustrated in Fig. 10. It consists of a hollow air-tight float *a*, suspended from a lever *b*. Within the body of the water column are guides that prevent the float from binding or sticking. When the

water falls in the column to a low level, the weight of the float *a*, acting through the vertical stem *c*, pulls the lever *b* down and thus opens the valve *d*, allowing steam to pass and sound the whistle *e*. When the water level rises sufficiently the float rises until the stop *f* engages the lever *b*, pushing it up. As this lever is double-acting, it operates the valve *d* by either an upward or a downward motion. The stop *f* is adjustable and can be set in any desired position on the rod *c*. The proper action of the signal can be tested by opening the drain valve attached at *g*, which will drain the water and allow the float to fall and sound the whistle. Gauge-cocks *h* and a gauge glass *i* are connected to the body of the water column, as shown. The device is connected at *j* with the steam space of the boiler and at *k* with the water space.

28. Gauge-Cocks.—A gauge-cock is a simple cock or valve attached either directly to the boiler, or, preferably, to a water column, for the purpose of testing the level of the water in the boiler. Three gauge-cocks are generally employed. The lowest is placed at the lowest level that the water may safely attain, and the uppermost at the highest desirable level. The third cock is placed midway between the other two. On opening a cock above the water level, steam will issue forth, and on opening one below the water level, water will appear. Hence, the level may be easily located by opening the cocks in succession.

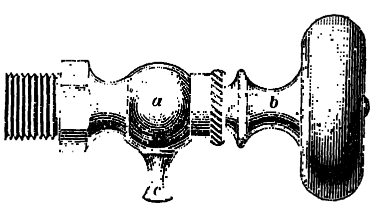


FIG. 11

29. The gauge-cock most commonly used is of the compression type. Such a cock, with a wooden hand wheel, is shown in Fig. 11. It consists of a brass body *a* having a threaded shank for attaching it to the boiler or water column. The seat within the body is closed by the end of the threaded valve stem *b*. The steam or water issues from the nozzle *c* when the cock is opened. Compression gauge-cocks can be obtained with a lever handle in the form of a crank. Such

cocks can be operated from a distance by means of a rod. In some designs the valve is held to its seat by a strong spring, which automatically closes the valve the moment the hand releases it.

30. A weighted gauge-cock, known to the trade as a *Register pattern cock*, is shown in Fig. 12. It consists of a body *a* having a threaded shank for attaching it to the boiler or the water column. The weight *b* is pivoted at *c* to the body, and when down presses a strip *d* of soft-rubber packing against the face of the opening at *e*. The cock is opened by lifting the weight slightly, and the issuing steam or water is deflected downwards by the curved end wall of the slot. In order to show the construction clearly, the weight is shown raised to the full limit. The strip of soft-rubber packing is simply pushed through two opposite slots. It must be renewed frequently, as it rots under the high temperature to which it is subjected in service.

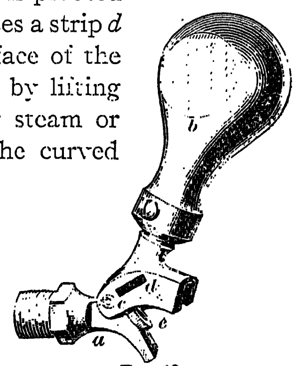


FIG. 12

31. Glass Water Gauges.—The gauge glass is a glass tube whose lower end communicates with the water space of the boiler and whose upper end is in communication with the steam space; hence, the level of the water in the gauge glass should be the same as in the boiler. Fig. 13 shows a common method of connecting a gauge glass *a*. The lower fitting *b* opens into the water space, and the upper fitting *c* into the steam space of the boiler. A drip cock *d* is placed at the lower end of the glass for the purpose of draining it. Two brass rods *e* tend to protect the gauge glass against accidental breakage. The fittings may be screwed directly into the boiler. The gauge should be so located that the water will show in the middle of the gauge glass when at its proper level in the boiler. Both fittings have cocks *f* by means of which communication with the boiler can be shut off and the escape of steam and water prevented in case the gauge glass breaks.

32. Automatic Safety Water Gauges.—To prevent loss of steam and water, and to obviate the danger of scalding the workman who tries to close the valves, it is desirable to have water gauges that will automatically shut off communication with the boiler whenever the gauge glass breaks. There

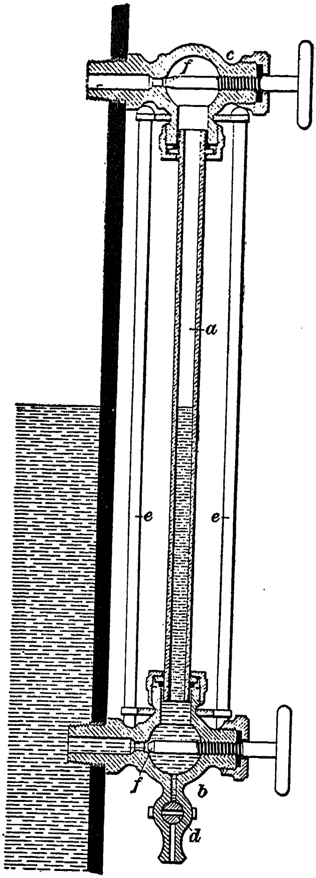
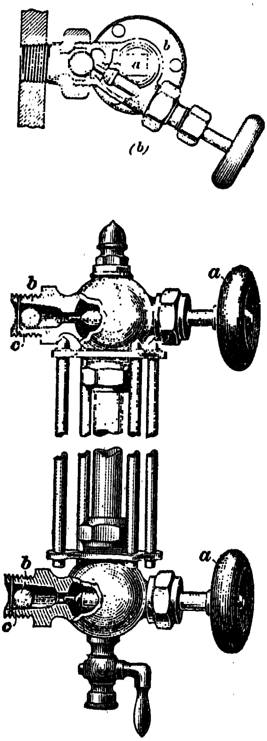


FIG. 13



(a)

FIG. 14

are many designs of such valves on the market. Fig. 14 (*a*) is a typical automatic pattern with hand-control valves *a*. A ball *b* is placed within the shank of each fitting, and is prevented from falling out by a brass pin *c*. Should the gauge

glass break, the outward rush of steam and water will carry the balls forward and thus close the openings leading to the gauge glass. The balls close the gauge-glass openings sufficiently to permit the hand valves *a* to be closed without danger of scalding the boiler attendant. The shut-off valve at the top of the gauge-glass fitting may be offset, as shown in the

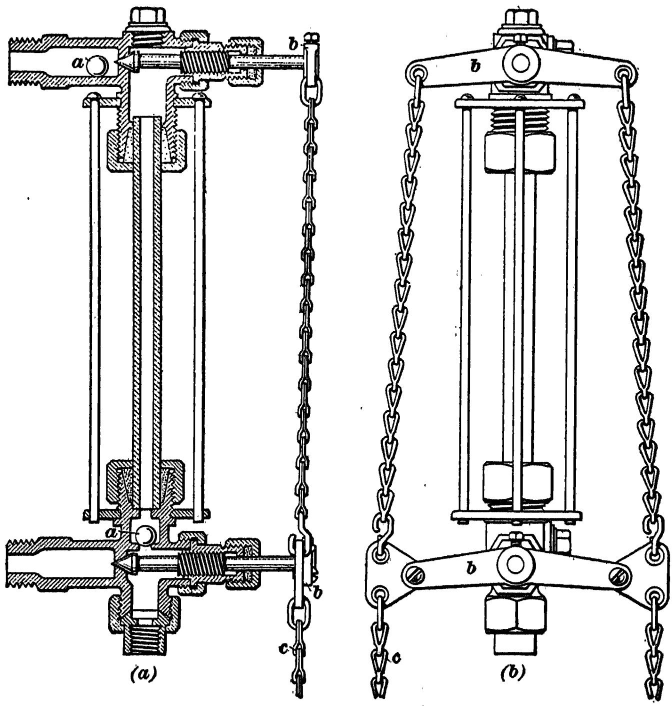


FIG. 15

plan view (*b*), so as to enable the glass to be inserted or removed easily. A plug *a* is screwed into the fitting *b* directly over the gauge glass. When this plug is removed and the packing nuts on the glass have been loosened, the glass may be pushed straight up through the top fitting.

To avoid entirely the danger of scalding the hands, the lever type of safety water gauge, with automatic ball control,

as shown in Fig. 15 (*a*) and (*b*), may be used. The balls are arranged as shown at *a* in the cross-sectional view (*a*) and work on the same principle as in Fig. 14, in case of glass breakage. The levers *b*, Fig. 15, are operated by chains *c* and the valves are closed and opened by pulling the chains.

33. Water Column.—A common form of water column is shown in Fig. 16. It consists of a hexagonal cast-iron standpipe *a* tapped at the top and the bottom for pipe connections to the boiler. Tapped bosses are provided, which receive the threaded shanks of the gauge-glass fittings *b* and the gauge-cocks *c*. Each maker has his own style of standpipe, the different makes varying chiefly in the ornamentation. The steam gauge is frequently mounted on top of the water column.

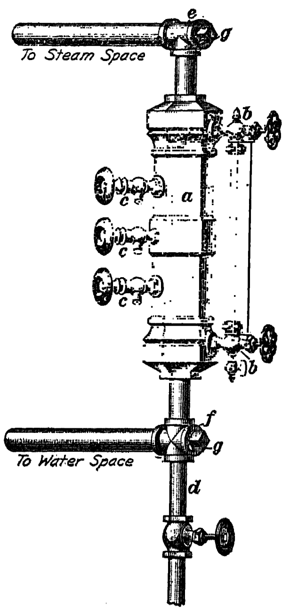


FIG. 16

In certain States, it is not allowable to place valves in the piping between the water column and the boiler, because of the danger that such valves may be closed and thus cause incorrect indication of the water level, with the possibility of serious consequences. Yet it is convenient to have shut-off valves, to avoid the necessity of closing down the boiler in case of accident to the water column. If such valves are installed, the fireman should make sure that they are fully open when the boiler is in operation. The pipe connections to the water column should not be less than $1\frac{1}{4}$ inches in diameter.

34. Water-Column Connections.—The connection to the boiler should be made with a **T** on the top, as at *e*, Fig. 16, and a cross *f* on the bottom, with the unused openings plugged with brass plugs *g*. If the connections are made in this manner,

they can be cleaned with a rod when the plugs are unscrewed. A drain pipe *d* with a valve in it, and leading to the ash-pit, should always be provided for the standpipe, and should be frequently used for blowing out sediment collecting in the standpipe. For low-pressure boilers no valves need be placed in the pipes leading to the steam and water spaces of the boiler; for high-pressure boilers, however, valves should always be provided. These valves are used in blowing out the standpipe and connections. Closing the valve in the upper pipe and opening the valve in the drain pipe blows out the lower pipe; closing the valve in the lower pipe and opening the valve in the drain pipe blows out the upper pipe and the standpipe.

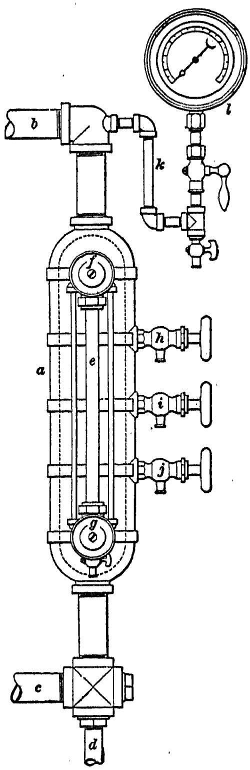


FIG. 17

35. An arrangement of water column, gauge glass, gauge-cocks, and steam gauge recommended by the Hartford Boiler Insurance Company is shown in Fig. 17. The round cast-iron column *a* has an inside diameter of about 4 inches. The upper end communicates with the steam space of the boiler by means of the pipe connection *b*, and the lower end with the water space through the pipe connection *c*. A drip pipe *d* is used for removing the water from the column occasionally in order to prevent it from becoming clogged. The gauge glass *e* communicates with the column through the connections *f* and *g*. The gauge-cocks *h*, *i*, and *j* are attached to the water column; a siphon *k* protects the steam gauge *l*.

36. Installation of Gauge Glasses, Gauge-Cocks, and Water Columns.—The Boiler Code of the American Society of Mechanical Engineers specifies the following requirements

for the installation of gauge glasses, gauge-cocks, and water columns:

Each boiler shall have at least one water-gauge glass, the lowest visible part of which shall be not less than 2 inches above the lowest permissible water level. The lowest permissible water level for various classes of boilers shall be the location for the fusible plug.

Automatic shut-off valves on water gauges, if permitted to be used, shall conform to the following requirements:

(*a*) Check-valves in upper and lower fittings must be of the solid non-ferrous ball type to avoid corrosion and the necessity for guides.

(*b*) Ball check-valves in upper and lower fittings must open by gravity, and the lower check-valve must rise vertically to its seat.

(*c*) The check balls must not be smaller than $\frac{1}{2}$ inch in diameter, and the diameter of the circle of contact with the seat must not be greater than two-thirds of the diameter of the check ball. The space around each ball must not be less than $\frac{1}{8}$ inch, and the travel movement from the normal resting place to the seat must not be less than $\frac{1}{4}$ inch.

(*d*) The ball seat in the upper fitting must be a flat seat with either a square or a hexagonal opening, or otherwise arranged so that the steam passage can never be completely closed by this valve.

(*e*) The shut-off valve in the upper fitting must have a projection which holds the ball at least $\frac{1}{4}$ inch away from its seat when the shut-off valve is closed.

(*f*) The balls must be accessible for inspection. Means must be provided for removal and inspection of the lower ball check-valve, while the boiler is under steam pressure.

When shut-offs are used on the connections to a water column, they shall be either outside-screw and yoke-type gate valves or stop-cocks with levers permanently fastened thereto and marked in line with their passage, and such valves or cocks shall be locked or sealed open.

Each boiler shall have three or more gauge-cocks, located within the range of the visible length of the water glass, except when such boiler has two water glasses with independent connections to the boiler and located on the same horizontal line and not less than 2 feet apart.

No outlet connections, except for damper regulator, feed-water regulator, drains, or steam gauges, shall be placed on the pipes connecting a water column to a boiler.

PRESSURE GAUGES

37. Steam Gauge.—The steam gauge, the face *a* of which is shown in Fig. 18, indicates the pressure of the steam contained in the boiler. The most common form is the *Bourdon pressure gauge*, the distinguishing feature of which is a bent elliptical

tube that tends to straighten out under an internal pressure. Bourdon pressure gauges are made in various ways by different manufacturers; a very common design is shown in Fig. 19. It consists of a two-branched bent tube *a*, of elliptical cross-section, that is filled with water and connected at *b* with a pipe leading to the boiler. The two ends *c* are closed and are are attached to a link *d*, which is, in turn, connected with a quadrant *e*; this quadrant gears with a pinion *f* on the axis of the index or pointer *g*.

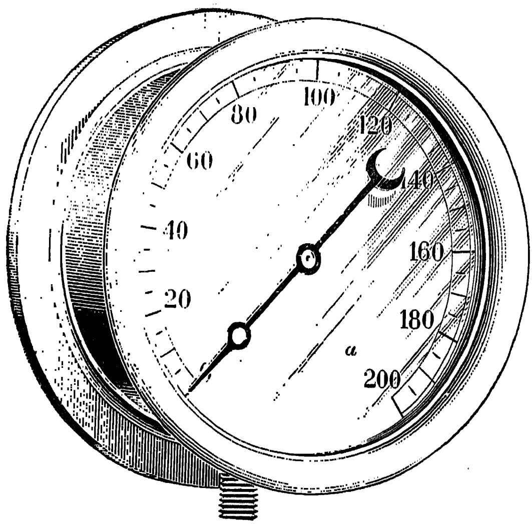


FIG. 18

38. When the water contained in the elliptical tube *a*, Fig. 19, is subjected to pressure, the tube tends to take a circular form, and, as a whole, straightens out, throwing out the free ends to a distance proportional to the pressure. The movement of the free ends is transmitted to the pointer by the link, quadrant, and pinion, and the pressure is thus recorded on a graduated dial in front. The illustration shows the gauge with the dial removed in order to display the mechanism. This type is especially adapted for stationary, marine, and portable boilers subjected to a great deal of vibration.

The single-tube steam gauge, shown in Fig. 20, consists of a tube *a*, the free end of which is connected to a lever *b* attached to a toothed sector *c* that moves a small pinion on the pointer shaft *d*. Lost motion is prevented by the action of a small hair-spring *e*, which is also used in steam gauges of the double-tube type.

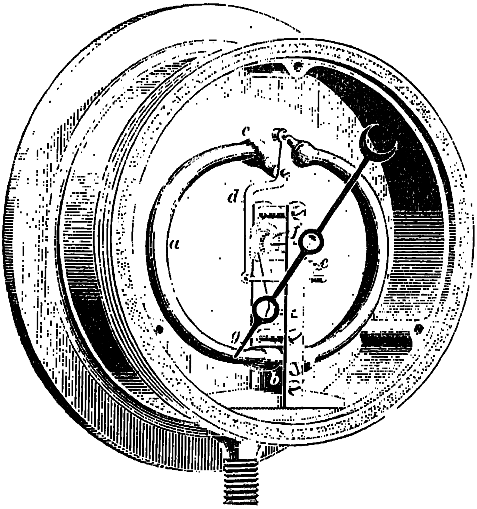


FIG. 19

Pressure gauges for indicating steam pressure are graduated to show the pressure above that of the atmosphere, in pounds per square inch, wherever the English system of weights and measures is used.

39. Steam-Gauge Siphons.—A steam gauge must be connected to the boiler in such a manner that it will not be injured by heat nor indicate the pressure incorrectly. To prevent injury from the heat of the steam, a siphon may be used to connect the steam gauge to the steam space of the boiler. The siphon may be arranged as shown in Fig. 21 (*a*) and (*b*), or as in Fig. 22. Within a short time after the steam gauge is

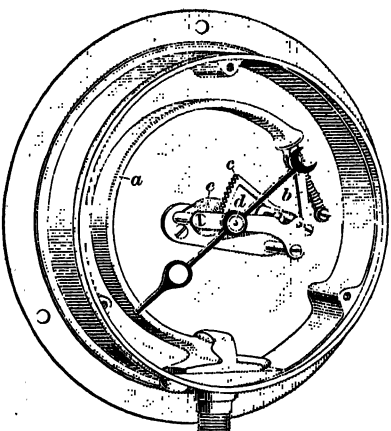


FIG. 20

put into use, the siphon becomes filled with water formed by the condensation of steam. The water protects the tube of the gauge from injury that would result if the hot steam had free circulation in the tube. Temperatures above 150° F. may affect the elasticity of the tube and thus impair the accuracy of the gauge. The steam-gauge pipe should not be connected to the main steam pipe leading from the boiler, nor should it be located near the outlet of that pipe, as this may cause the gauge to indicate a lower pressure than really exists in the boiler. The gauge should be connected to the siphon as

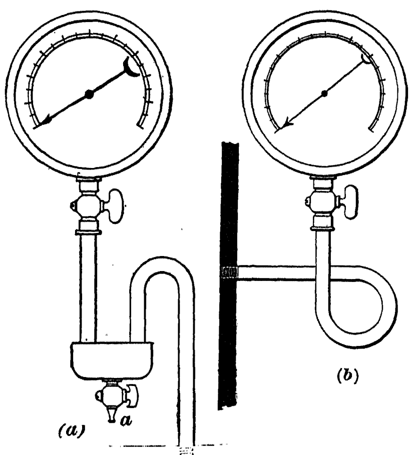


FIG. 21

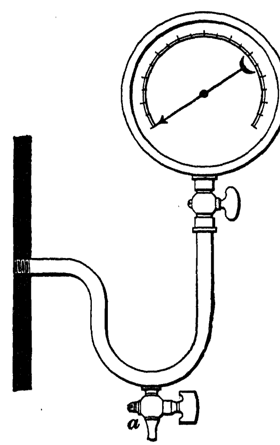


FIG. 22

indicated in the illustrations so that the water which accumulates in the siphon does not act to increase the pressure.

The siphons shown in Fig. 21 cannot be drained without disconnecting them from the boiler. To overcome this disadvantage, a petcock, as shown at *a*, Figs. 21 (*a*) and 22, may be placed at the lowest point of the siphon. The petcock should not be opened while the steam gauge is in service, as then the water seal would be lost and the tube would be damaged by the steam.

40. Testing Steam Gauges.—A steam gauge will lose its accuracy after it has been in use for some time, owing to the

fact that the tube loses its elasticity and takes a permanent set. In this case the gauge will indicate a pressure higher than the actual pressure in the boiler. This can usually be discovered by the failure of the pointer to return to the zero mark when there is no pressure in the boiler. If the pressure apparently indicated when there is no pressure is subtracted from the pressure indicated when the boiler is under steam, the correct pressure will be given approximately. However, when a gauge shows a wrong pressure, a new one should be immediately substituted and the old one discarded or sent to the maker for repair.

When inspecting boilers, the inspectors of boiler-insurance companies or municipal boiler inspectors usually test all steam gauges in the plant by comparison with an accurate test gauge. The gauge to be tested and the test gauge are both attached to a vessel in which the pressure is raised by means of a small force pump, and the readings of the two gauges at different pressures are compared.

41. The safety valve can be checked by means of the steam gauge when the latter is known to be accurate. Conversely, when the safety valve is known to be set correctly, the steam gauge can be checked for the blow-off pressure by watching its indication when the valve just blows off. If a steam gauge shows an error of more than 5 pounds, it will be condemned by most boiler inspectors. The steam gauge should be taken off periodically and the connecting pipe cleared by blowing steam through it. When the gauge is off, care should be taken to see that the hole in the nipple is perfectly clear.

Good practice demands that a steam gauge should be attached to each boiler, when more than one boiler is used. In some regions, however, it is not uncommon to see one steam gauge do duty for a whole battery of boilers. Such an arrangement has nothing but cheapness to recommend it and is severely condemned by engineers and insurance companies.

42. When the boiler supplies steam to a steam engine, it sometimes happens that, when the engine is running, the pointer of the steam gauge vibrates so much that the pressure

cannot be read. This can be prevented by partly closing the petcock shown below the gauges in Figs. 21 and 22. The greatest care must be taken, however, to prevent entire closing of the cock. The pointer of a steam gauge will stick occasionally; hence, experienced engineers always jar the gauge a little, in order to dislodge anything that may be preventing movement of the pointer, before they accept its indication as correct.

43. The spring tube of a steam gauge is liable to corrode when certain kinds of water are used. Under no circumstances should an attempt be made to fix a corroded tube by soldering up the hole or holes; instead, the gauge should be sent to the maker to have a new tube fitted and adjusted. When a gauge has been taken off, it should not be replaced without making sure that the passage through the cock on the steam-gauge pipe is clear when the cock is in the open position. Care should also be taken to see that the gauge is free to operate after it has been replaced. It has happened that, when the piping was being put up, the gasket placed between the two parts of the union was so large that in tightening the nut it was squeezed out so as to stop the hole in the pipe completely, thus preventing the gauge from showing the pressure.

44. Rules for Installation and Use of Steam Gauges.—The rules given by the A. S. M. E. Boiler Code for the installation of steam gauges are as follows:

Each boiler shall have a steam gauge connected to the steam space or to the water column or its steam connection. The steam gauge shall be connected to a siphon or equivalent device of sufficient capacity to keep the gauge tube filled with water and so arranged that the gauge cannot be shut off from the boiler except by a cock placed near the gauge and provided with a tee or lever handle arranged to be parallel to the pipe in which it is located when the cock is open. Connections to gauges shall be of copper, brass, or bronze composition.

Where the use of a long pipe becomes necessary, an exception may be made to the rule that the gauge must be arranged so that it cannot be shut off except by a cock placed near the gauge, and a shut-off valve or cock arranged so that it can be locked or sealed open may be used near the boiler. Such a pipe shall be of ample size and arranged so that it may be cleared by blowing out.

The dial of the steam gauge shall be graduated to approximately double the pressure at which the boiler will operate, but in no case to less than $1\frac{1}{2}$ times the maximum allowable working pressure on the boiler.

Each boiler shall be provided with a $\frac{1}{4}$-inch pipe size valved connection for the exclusive purpose of attaching a test gauge when the boiler is in service, so that the accuracy of the boiler steam gauge can be ascertained.

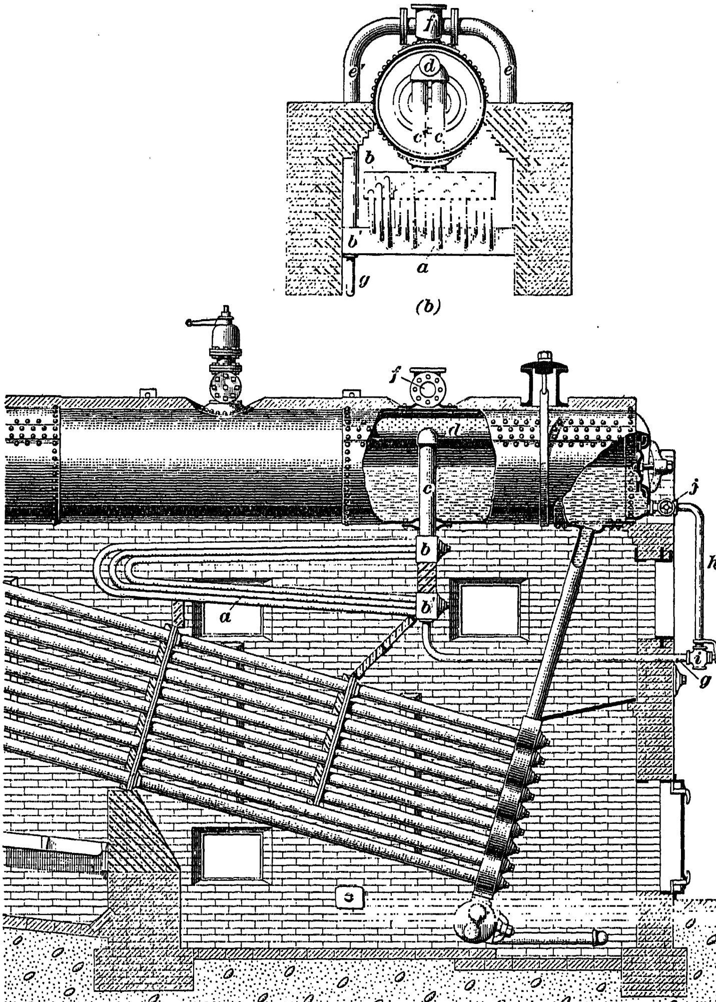
SUPERHEATERS

45. Purpose of Superheating.—Steam in contact with the water in a boiler has the same temperature as the water and is known as saturated steam. Additional water may be taken up by the steam through priming of the boiler or from the movement of the boiler, as in marine, portable, and locomotive boilers. Moisture also arises from condensation of the steam. Large heat losses result from the use of wet steam for power purposes, and there are other disadvantages in the effect of such steam on turbines, engines, etc. In turbines, water in the rapidly moving steam erodes, or wears away, the blades, and increases the amount of steam used. The same conditions arise in reciprocating engines, and there is a possibility of damaging the cylinder heads and the stuffingboxes around piston rods and valve stems.

46. The demand for greater economy in the performance of steam engines has led to the development of the superheater, by means of which the steam may be superheated to a moderate degree so that it will contain more heat and therefore do more work than would the same weight of saturated steam, and thus insure increased engine economy. In order to superheat the steam, it must pass from the boiler into a separate compartment and have more heat applied to it. This may be done with a separate furnace or by using a coil of pipe within the boiler setting itself; or, the superheater may be arranged in the smokebox of a locomotive boiler, or in the uptake leading to the stack in other boiler installations.

47. Wrought-Iron Superheater.—One form of superheater, as arranged in connection with a water-tube boiler, is shown in Fig. 23 (*a*) and (*b*). It consists of a number of bent wrought-

iron tubes a with their ends expanded into headers b, b', and is located in the upper part of the combustion chamber of



(a)

FIG. 23

the boiler. The upper header b is connected with the dry pipe d by two vertical pipes c, c', while the lower header b' is con-

nected by means of two pipes *e*, *e′*, to the steam outlet *f* on top of the boiler. The steam is drawn from the dry pipe through the pipes *c*, *c′* to the upper header *b*, thence through the superheater tubes *a* to the lower header *b′*, and up the external pipes *e*, *e′*, to the steam outlet *f*. The lower header *b′* is connected to the water space of the boiler by means of the pipes *g* and *h*, fitted with valves *i* and *j* for the purpose of filling the superheater with water when not in use, as is the case when getting up steam or when the engine is not running. To put

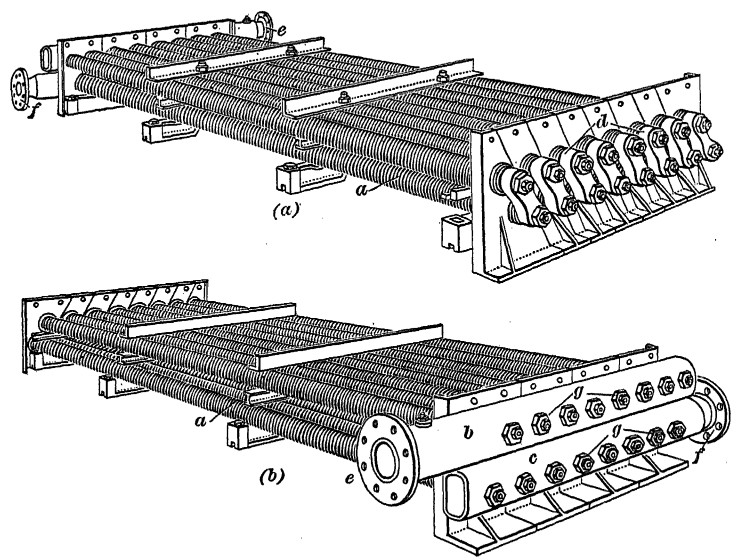


FIG. 24

the superheater into service, the water is drained from it by means of the three-way valve *i*. Not all superheaters have provision made for flooding while steam is being raised. In many cases a valve on the superheater is opened, allowing air and steam to escape from the superheater until full pressure on the boiler is reached, when the valve is closed and the superheater is cut into service.

48. Foster Superheater.—The Foster superheater, two views of which are shown in Fig. 24 (*a*) and (*b*), consists of a

series of straight seamless steel tubes, over which are slipped a large number of cast-iron rings *a*; these cover the tubes with cast-iron fins that absorb the heat and conduct it to the tubes. At the same time, the cast-iron rings prevent the tubes from burning out and protect them from the corrosive action of the furnace gases. The steel tubes are expanded into the headers *b* and *c* and at the other end are joined by the tube fittings *d*. Steam enters the header *b* at *e*, flows through the upper bank of tubes, down through the fittings *d*, back through the lower bank of tubes into the header *c*, and out at *f*. Handholes *g* are provided in the headers *b* and *c* and in the fittings *d* opposite the tubes. A cross-section through one of the handhole plugs is shown in Fig. 25. The plug *a* is tapered and is in one piece with the stud *b*. A copper gasket *c* is inserted between the plug and the tapered seat, the yoke *d* is set over the stud, and the plug is drawn to its seat by the nut *e*. The form of superheater shown in Fig. 24 is so arranged in the boiler setting that the headers *b* and *c* and the fittings *d* are accessible from the outside of the boiler, thus making it easy to remove the handhole plugs for cleaning, inspecting, or repairing the superheater.

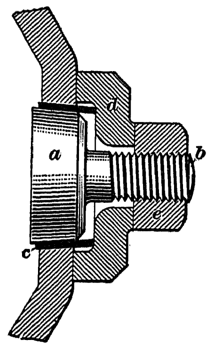


FIG. 25

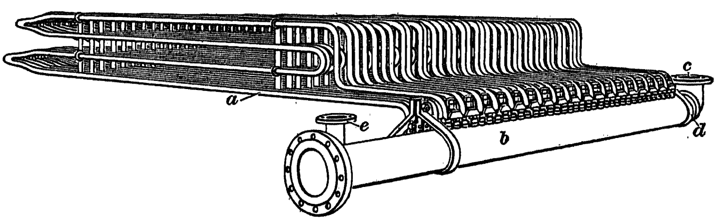


FIG. 26

49. Elesco Superheater.—A form of superheater for stationary boilers is shown in Fig. 26. It consists of a large number of cold-drawn seamless steel tubes *a* attached to two headers *b* and *c*. The tubes are bent, as shown, so as to provide

a large amount of surface to be exposed to the hot gases, and at the same time to take care of the expansion and contraction. Saturated steam from the boiler enters the header *b*, which is closed at the end *d*, and flows through the banks of piping *a*, wherein it is superheated. It then passes out of the tubes *a* into the header *c*, which lies behind the header *b*, and which is also closed at one end. The flange *e* on the header *b* forms a connection for the installation of the safety valve.

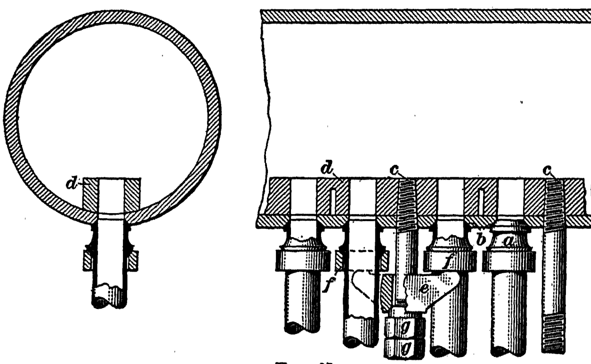


FIG. 27

50. The ends of the tubes are connected to the headers by metal-to-metal joints, as shown in the sectional view, Fig. 27. The end *a* of each tube is formed by a special forging process and is then ground to an angle of 45° to fit the conical seat in the header, as shown at *b*. Between each pair of tubes is a stud *c* that passes through the wall of the header into a reinforcing strip *d*. A two-armed clamp *e* is slipped over the stud, and its ends bear against the collars *f* on the tubes. When the clamp is forced against the collars by screwing up the nuts *g* on the stud, the ends of the tubes are held tightly in the conical seats in the header. This construction enables the tubes to be removed or replaced with little labor or loss of time.

BOILER DETAILS
(PART 1)

FIRE-TUBE AND WATER-TUBE BOILER DETAILS

RIVETED JOINTS

RIVETS AND RIVETING

1. Forms of Rivets.—The plates that form steam boilers are fastened together by rivets. A rivet is a piece of soft iron or steel rod with a head formed at one end. The cylindrical part of the rivet is called the *shank;* it is inserted into a hole drilled or punched through the plates to be joined, and its end is then hammered or pressed to form a second head, the plates being gripped and held firmly between the heads. The most common forms of rivet heads are shown in Fig. 1, and the dimensions are given in terms of the diameter d of the shank. From these dimensions it is easy to calculate the proportions of a rivet head of any type for any diameter of rivet shank. For example, suppose that the dimensions of the head shown in (*a*) are required for a rivet whose shank is $\frac{3}{4}$ inch in diameter. As $d=\frac{3}{4}$ inch, the height of the head is $.75\ d=.75\times.75=.5625$ inch, or $\frac{9}{16}$ inch, and the diameter of the head is $1.75\ d=1.75\times.75=1\frac{5}{16}$ inches.

2. The proportions of rivets shown in Fig. 1 are in accordance with the A. S. M. E. Boiler Code, but a variation of 10 per cent. is permissible; that is, any dimension may be

as much as one-tenth larger or smaller than that indicated. In boiler, plate, and tank work, various forms of rivets are used, and their names are derived from the shapes of their heads. Of the several forms shown in the illustration, those in (*b*),

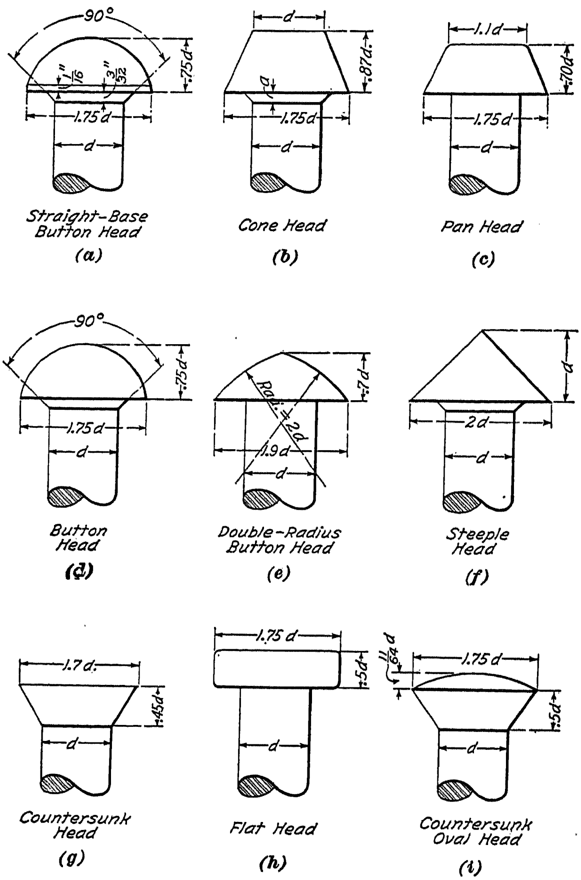


FIG. 1

(*c*), (*d*), (*e*), and (*g*) are most commonly used in boiler construction. The cone-head rivet is slightly tapered under the head, the depth *a* of the tapered part being $\frac{1}{32}$ inch for rivets from $\frac{1}{2}$ inch to 1 inch in diameter and $\frac{1}{16}$ inch for rivets greater than 1 inch in diameter. The outer edge of the rivet

hole is correspondingly beveled, or chamfered, when this form of rivet is used, as shown in Fig. 2 (*a*), thus removing the sharp corner around the hole and making a good seat for the rivet head. Frequently this form of rivet is driven, or headed, by the use of tools that form button heads on both ends, instead of on one end only, as shown in (*b*); it has proved to be a very good form to obtain steam-tight joints.

3. The double-radius button-head rivet, shown in Fig. 1 (*e*), and known also as the conoid-head rivet, is another very good form. In fact, it is generally believed to be superior to the button-head type, as it is easily made tight in the plate and remains so. The countersunk rivet, shown in (*g*), is used in riveted joints when it is undesirable to have rivet heads project above the surface, where they might interfere with the placing of plates or other parts in their correct positions. The flat-head rivet, shown in (*h*), is also used for some connections of the same kind, but is more extensively employed in lighter sheet-metal work, such as breechings, stacks, and boiler casings. The rivet holes in plates are made from $\frac{1}{32}$ to $\frac{1}{16}$ inch larger in diameter than the rivet shank, so that the rivet may be inserted readily.

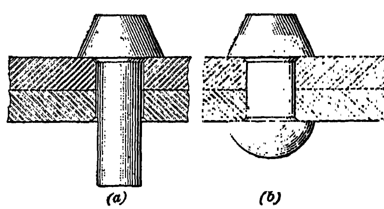


FIG. 2

4. Methods of Riveting.—The act of joining pieces of metal by means of rivets is known as riveting; and it consists of passing a rivet through holes in the metal and then forming a second head. That part of the shank from which a second head is formed is usually known as the *neck* of the rivet. The rivet head may be formed entirely by hammering with a light hammer, in which case the process is called *hand riveting*.

If the head is formed by striking a die with a heavy hammer, the process is called *snap riveting*, which is a modification of hand riveting; the *die*, which is called a *set*, or *snap*, is a piece of hardened steel hollowed out to the desired form of head. If the head is formed by striking comparatively light,

but very rapid blows, with an *air hammer,* or *pneumatic hammer,* the process is called *pneumatic riveting.* If the head is formed by squeezing, or upsetting, the metal of the neck under high pressure in a machine, the process is called *machine riveting;* and if the machine is operated by hydraulic pressure, the process is called *hydraulic riveting,* or *bull riveting.*

5. For boiler work in general, machine riveting has important advantages over hand riveting, and it is now employed wherever possible. The advantages are as follows: (*a*) A tighter joint can be made for the reason that the plates that are being riveted can be held together with greater force while the second rivet head is being formed. (*b*) The holes in the plates can be filled better, because the shank is made to spread out by the pressure applied to upset the rivet and to form the head. (*c*) It is faster and cheaper, if many rivets are to be driven.

FORMS OF RIVETED JOINTS

6. Terms Used in Riveted Work.—If a joint is formed by having the edges of two plates overlapped and joined by one or more rows of rivets, it is called a *lap joint.* If the plates are placed edge to edge and the junction or seam is covered with a narrow strip of boiler plate, called a *strap,* on either one or both sides of the plate, and the whole is riveted together, the joint is called a *butt joint.* The strap is also known as a *cover-plate,* a *welt,* or a *butt strap.* The terms *seam* and *joint* mean the same when applied to riveted connections. Riveted joints are also classified, according to the number of rows of rivets in the seam, as *single-riveted, double-riveted, triple-riveted,* and *quadruple-riveted joints,* and from the arrangement of the rivets in the joint as *staggered-riveted* and *chain-riveted joints.* A single-riveted lap joint is shown in Fig. 3. The distance between rivet centers, measured in the direction

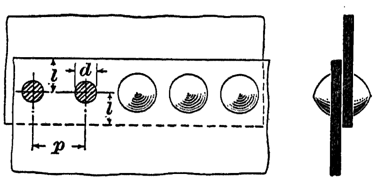


FIG. 3

of the length of the seam, is the *pitch* of the rivets, and the *lap* is the distance *l* from the center of the rivet hole to the edge of the plate.

7. Double- and Triple-Riveted Lap Joints.—Two different forms of double-riveted lap joint are shown in Fig. 4, that

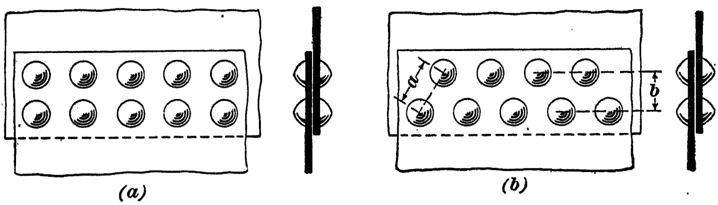


FIG. 4

in (*a*) being chain-riveted and that in (*b*) staggered-riveted. In a joint having chain riveting, the rivets in one row are directly opposite those in the next row; but, if staggered riveting is used, the rivets in one row are opposite the centers of the spaces between the rivets in the adjacent row. A joint with staggered riveting is often referred to as a *zigzag-riveted joint*. The diagonal distance *a* from the center of one rivet to the center of the next rivet in the adjacent row is called the *diagonal pitch*. The distance *b* between the center lines of adjacent rows of rivets is the *back pitch;* it is measured at right angles to the direction of the seam.

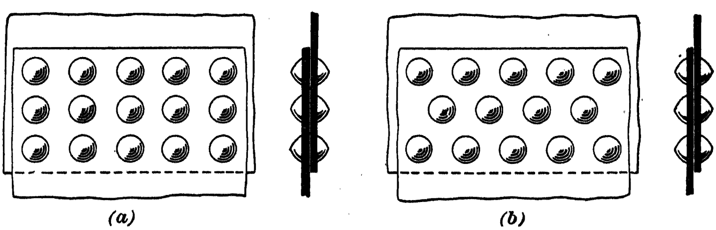


FIG. 5

Two types of triple-riveted lap joint are shown in Fig. 5, that in (*a*) having chain riveting and that in (*b*) staggered riveting. Quadruple-riveted lap joints have four rows of rivets and either chain or staggered riveting may be used.

Triple-riveted and quadruple-riveted lap joints are now seldom used in boiler work. Formerly such joints were used for longitudinal seams, but owing to the offset produced by overlapping the plate, difficulty arose in obtaining a true cylindrical shell. Another objection to such seams is that when the shell is under pressure, a bending action arises in the joint, which produces crystallized metal between the rivets. A correctly designed butt joint is superior to the lap joint in regard to strength and by its use the shell can be rolled to a true cylindrical form.

8. Single-Riveted Single-Strap Butt Joint.—A single-riveted butt joint with a single cover-plate *a* is illustrated in Fig. 6 (*a*) and (*b*). The ends of the boiler shell *b* are butted against each other, and in order to have the edges straight and parallel with each other they are machined on a plate planer. It will be seen that the joint has two rows of rivets *c* and yet is called a single-riveted butt joint. This follows from the fact that the separation of one plate from the other is opposed by only one row of rivets. Thus, if the plate is stronger than the rivets, the plates *b* can be separated only by shearing off the rivets. The pull on the joint, as shown by the arrows in (*a*), tends to break or tear the butt strap along the line *d d*, to crush or shear the metal in front of the rivets, as indicated by the dotted lines *e*, and to shear the rivets as shown at *f* in (*b*).

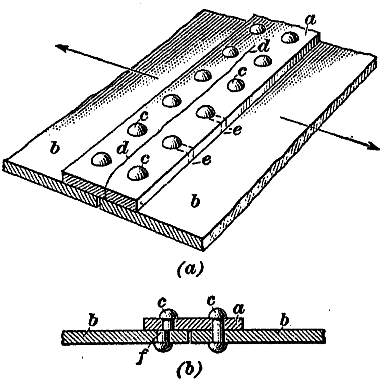


FIG. 6

Rivets driven through the plate and the butt strap and acted on by the pressure are in single shear, as the resistance of the rivet to shearing action is that of the sectional area of each rivet. Butt joints with single butt straps may be double-riveted, triple-riveted, etc., and the rivet arrangement may be chain or staggered.

9. Double-Strap Butt Joints.—The butt joint in Fig. 7 (*a*) consists of plates *a* that butt together at *b* and are joined by the use of two butt straps *c* and *d*. The outer strap *c* is narrower than the inner strap *d*. It will be noticed in the sectional view (*b*) that the outer strap is riveted to the plates and the inner butt strap by two rows of rivets, and that the inner

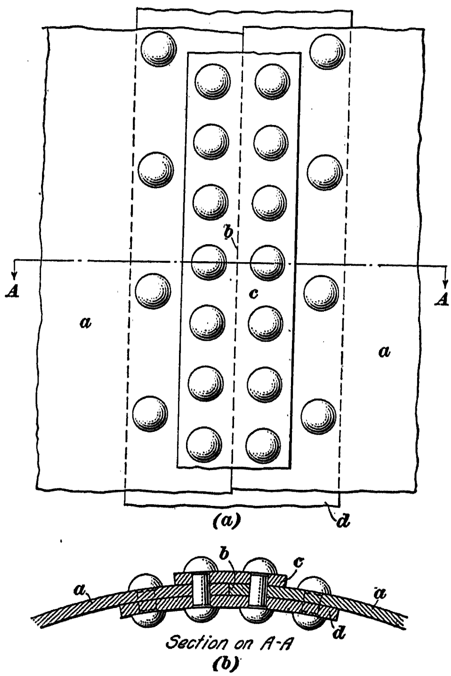


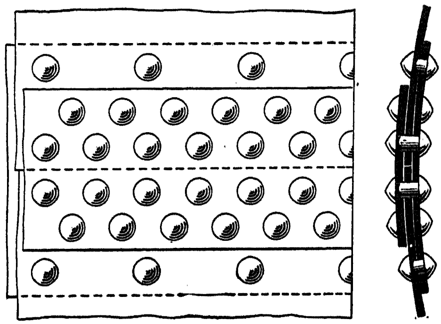
FIG. 7

strap is riveted to the plates by four rows of rivets, two rows being on each side.

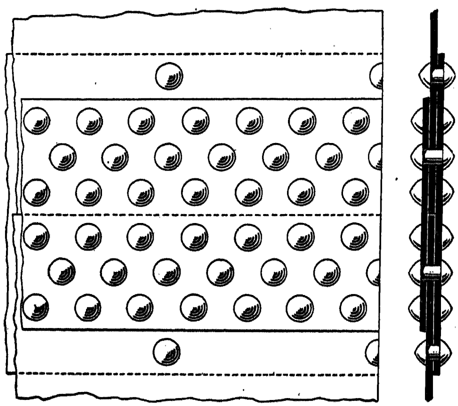
Butt joints may also be triple-riveted, as shown in Fig. 8 (*a*), or quadruple-riveted as in (b), with the rivets arranged according to the staggered or the chain method. The chief advantage of the double-strap butt joint having the outer strap narrower than the inner strap is that it may be designed to give a stronger form of joint than any other. The rivets are

usually staggered. The pitch of the rivets in the outer rows, which are in single shear, is double the pitch of the rivets in the inner rows.

10. Butt Joints With Straps of Equal Widths.—A triple-riveted double-strap butt joint with chain riveting is shown in



(*a*)



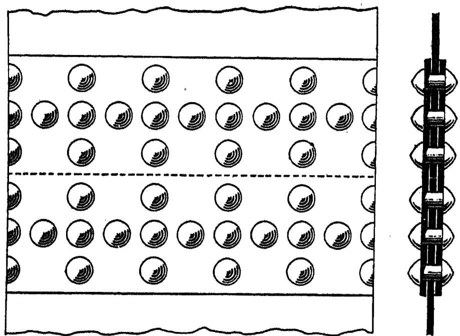
(*b*)

FIG. 8

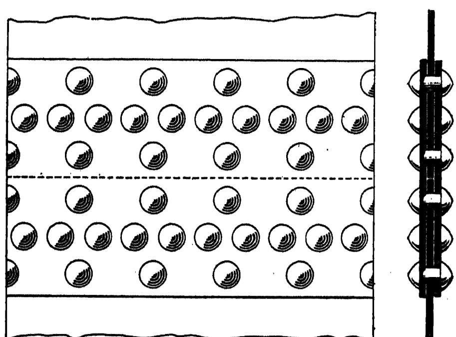
Fig. 9 (*a*) and the same type of joint with staggered riveting in (*b*). The inner and the outer butt straps are of the same width. On each side of the center line of the seam, indicated by the dotted line, there are three rows of rivets. The rivets

in the outer and the inner rows of these three have twice the pitch of the rivets in the center row.

Another form of double-strap butt joint, known as the *saw-tooth joint,* is shown in Fig. 10 (a) and (b). It is quadruple-riveted, and the outer strap a is cut to the outline indicated,



(a)

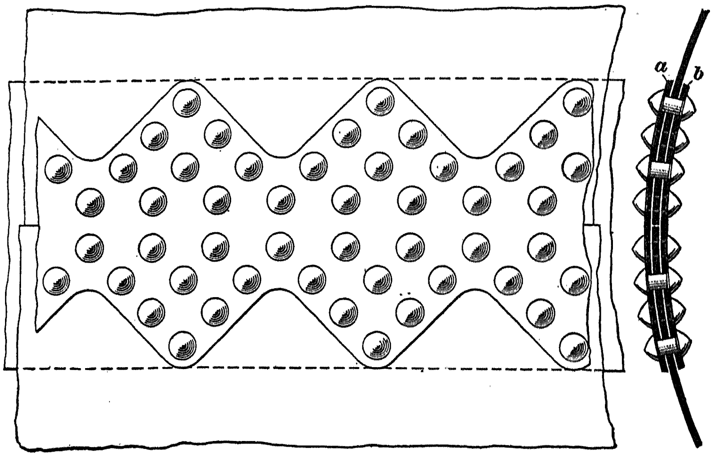


(b)

FIG. 9

the joint taking its name from the shape of this strap. The overall width of the strap a is the same as that of the inner strap b. This form of joint is more expensive to make than an ordinary double-strap butt joint and is seldom used in boiler practice, except for the shells of Scotch boilers; but it enables better calking to be done along the edges of the outer cover-

plate. By calking, is meant the forcing of the edge of the plate or rivet into close contact with the plate, so as to produce a steam-tight joint. It should be observed that the rivets in a



(a) (b)

FIG. 10

double-strap butt joint are in double shear; that is, it is necessary to shear each one along two sections to tear the joint apart by shearing off the rivets.

ARRANGEMENTS OF RIVETED JOINTS

11. Location of Longitudinal Seams in Shell Boilers. Owing to the high furnace temperatures, the eroding action of the fuel gases, and the number of overlaps in the plates, it is customary to locate the longitudinal seams of shell boilers as far as possible from the fire. Shell boilers of the horizontal return-tubular type usually have two or more sections, or *courses,* with only one longitudinal seam to the course. The longitudinal seams are so arranged that they *break joints,* or alternate, as shown at *a* and *a′*, Fig. 11; that is, the longitudinal seams in adjacent courses are not in one line, but one seam is to the right and the other to the left of the center. Each

seam is midway between the top and the side of the boiler. This arrangement of the seams permits the dome *b* to be installed, if one is required, and also the brackets *c*, without interfering with the joint construction.

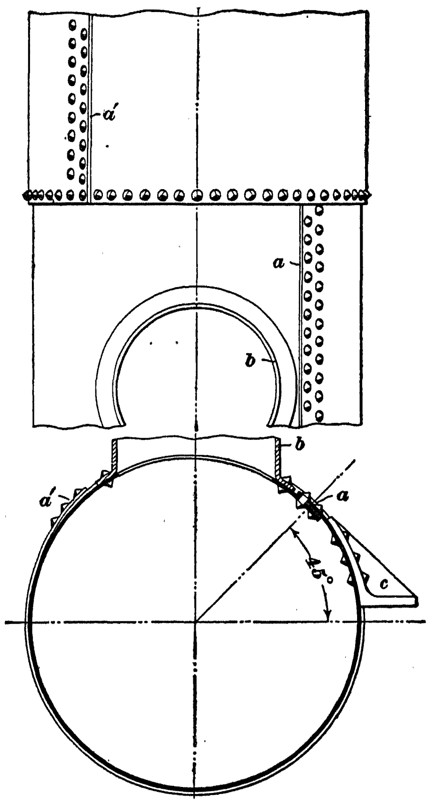


FIG. 11

12. Location of Longitudinal Joints in Internally Fired Furnaces.—In plain cylindrical furnace flues of internally fired boilers the longitudinal joint, as shown in Fig. 12, is generally located just below the grate, either to the right, as in the illustration, or to the left. The distance *s* is made as large as possible in order that the seam will not interfere with cleaning out the ashes.

In a vertical tubular boiler, the longitudinal (vertical) seam, if the boiler has only one course, may be located wherever convenient, provided it is clear of the fire-door opening. If the boiler has two or more courses, the longitudinal seams should break, or alternate.

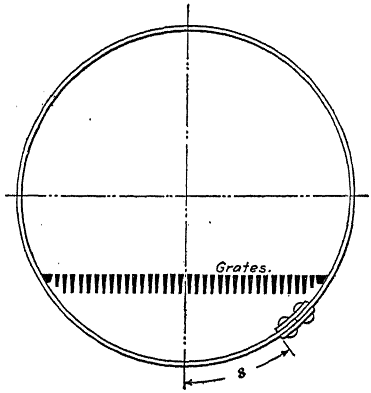


FIG. 12

13. Connecting Longitudinal Lap Joints at Girth Seam.—If plates lap together at the girth seams in boilers having longitudinal lap joints, the inner end *a*, Fig. 13, of the plate must be hammered out thin or scarfed, as it is commonly called, at the corner *b*. The outer end *c* of the plate is bent circular so as to fit the scarfed corner of *a*. If the lap joint is double zigzag-riveted, as shown, it is customary to make the pitch of all the rivets in the outer row uniform; in the inner row, the distance *d* from the rivet in the girth seam to the first rivet of the longitudinal seam will then be equal to 1½ times the pitch.

14. Connecting Single-Strap Butt Joint and Girth Seam. In the case of butt joints having single cover-plates, the junction of the longitudinal seam and the girth seam is made as shown in Fig. 14. The larger shell course *a* overlaps the smaller course *b*, thus forming the girth seam *c*. The butt strap *d* extends to the outer overlapping edge of the larger course *a* and the rivets *e* of the girth seam pass through the shell plates *a* and *b* and the strap *d*. In staggered riveting,

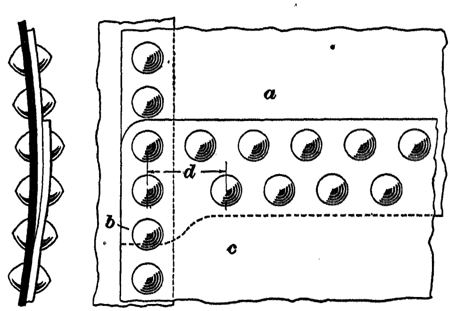


FIG. 13

the rivets in the butt joint adjoining the girth seam are usually pitched as explained in the preceding article.

15. In single-riveted longitudinal lap joints and butt joints it frequently is necessary, in order that the rivet die used on the inner head of the rivet may clear the inner edge *a*, Fig. 15, of the girth seam, to make the pitch *b* greater than the pitch of the rivets in the longitudinal seam. The inner end of the plate *c* is scarfed at the junction of the two courses, and the outer end of the plate *d* is bent to fit properly over the plate *c* and make a tight joint.

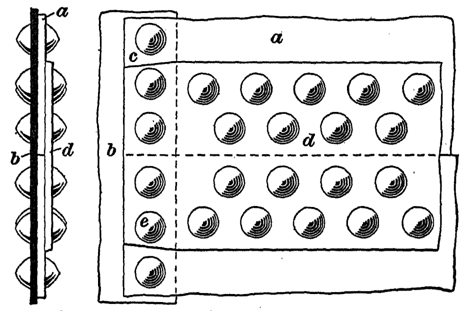


Fig. 14

16. Longitudinal Seam at Smokebox of Locomotive Boiler.—In boilers of the locomotive type, having double-strap butt joints, the joints at the smokebox end may be arranged as shown in Fig. 16. The end course *a* extends beyond the tube-sheet *b* so that the smokebox course *c* can be riveted to it. The tube-sheet *b* is flanged outwards so that it can be riveted to the shell courses *a* and *c*. From this arrangement of the tube-sheet, or head *b*, it is said to be *backed in*. The outer butt strap *d* at the smokebox end is flush with the outer edge of the flange of the head *b*, and the inner strap *c* is scarfed at the end to fit the curvature of the flange. The rivets in the girth seam at the smokebox end pass through the shell *a*, the flange of the head *b*, and the butt strap *d*.

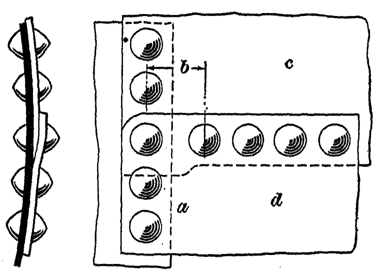


Fig. 15

The connection of the girth seam *f* and the longitudinal seam is made by extending the inner butt strap *e* to the edge of the course *a*. The external strap *d* is either made straight and butted against the plate *g* or else it is scarfed and placed under the larger course *g*. In the former case, sufficient space must

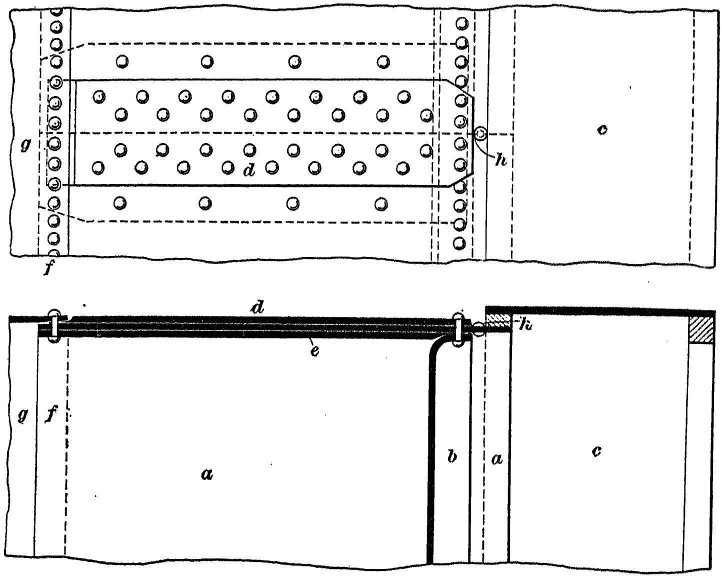


FIG. 16

be allowed between the shell and the butt strap for calking the seam. To prevent leakage at the junction of the butt joint and the smokebox, a *stop-rivet h* is used. It is usually a plug $\frac{3}{4}$ or $\frac{7}{8}$ inch in diameter, threaded and screwed tightly into the sheet *a*, after which both ends are formed into heads and then calked.

17. Connecting Double-Strap Butt Joint and Girth Seam. In a horizontal return-tubular boiler having three courses, as in Fig. 17 (*a*) and (*b*), the middle course *a* is slightly smaller in diameter and fits inside the two end courses *b* and *c*. The outer butt strap *d* of the longitudinal seam of the small course is scarfed at both ends and placed under the plate of the larger

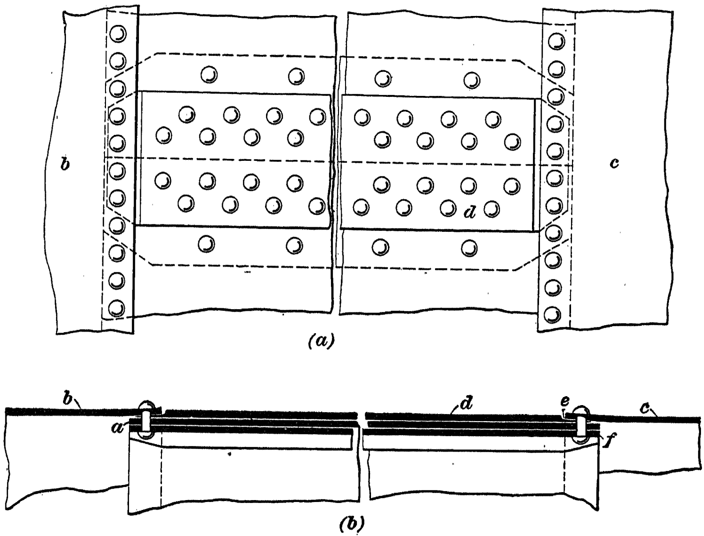


FIG. 17

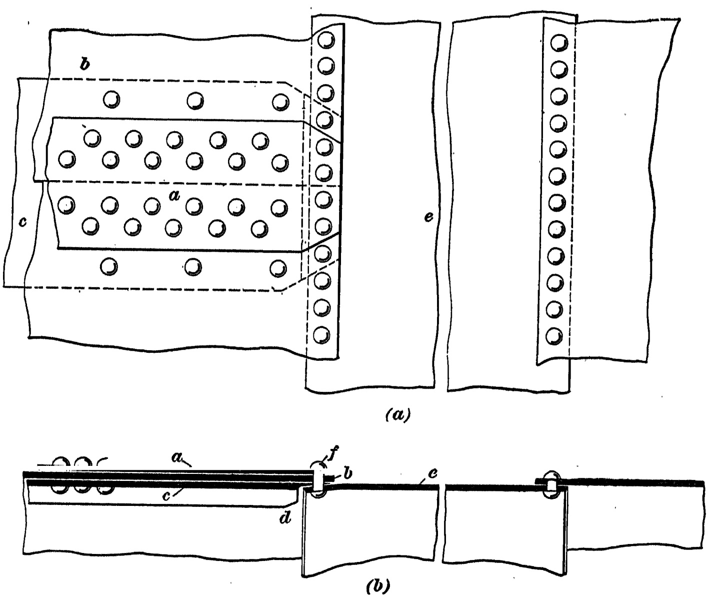


FIG. 18

courses *b* and *c* as shown at *e* in the sectional view (*b*). The inner butt strap *f* is not scarfed and extends the full length of the middle course *a*.

The arrangement of the girth seam and the longitudinal seams in the end courses is illustrated in Fig. 18 (*a*) and (*b*). The outer butt strap *a* is made equal to the length of the end course *b*. The inner butt-strap *c* is usually scarfed at both ends, as indicated at *d*. At one end it is passed over the flange of the tube-sheet and at the other end over the middle course *e*

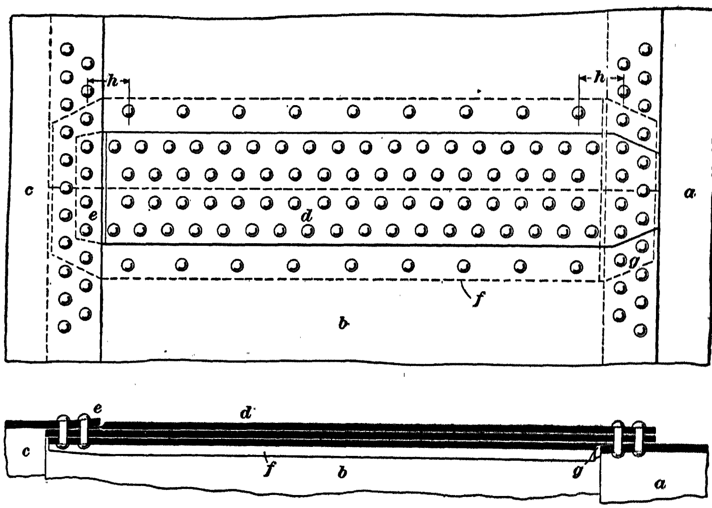


FIG. 19

at the girth seam *f*. In the return-tubular boiler, the heads or tube-sheets usually have their flanges placed inside the boiler; but there are types having the shell forming the smokebox as shown in Fig. 16, and in such a case the head at the smokebox end is backed in.

18. Seam Connections of Shells of Locomotive Boilers. An approved arrangement of the circumferential and longitudinal seams of the first, second, and third courses of a locomotive boiler is shown in Fig. 19. The circumferential seams are double-riveted and the longitudinal seams have double butt

straps, with the inner strap wider than the outer one, alternate rivets being omitted in the outer row. It is the usual practice to make the first course *a*, to which the front tube-sheet is riveted, the smallest; the second course *b* fits outside of the course *a*, and the third course *c* fits outside of the course *b*. The outer butt strap *d* of the longitudinal joint of the second course *b* is of full thickness at the girth seam between the courses *a* and *b*, but is scarfed sufficiently at the seam between the courses *b* and *c* to go under the first row of rivets, as shown at *e*. The plate of the course *c* is bent upwards slightly to give room for the scarfed end of the strap *d*. The inner butt strap *f* is of full thickness at the girth seam between the courses *b* and *c* and extends far enough to take both rows of rivets. At the girth seam between the courses *a* and *b*, the butt strap is scarfed, as shown at *g*, and lies on top of the first course, the plate *a* being bent downwards slightly to accommodate the scarfed end of the strap *f*. The distance *h* from the girth-seam rivets to the first rivet in the outer row of the longitudinal seam should be the same at both ends.

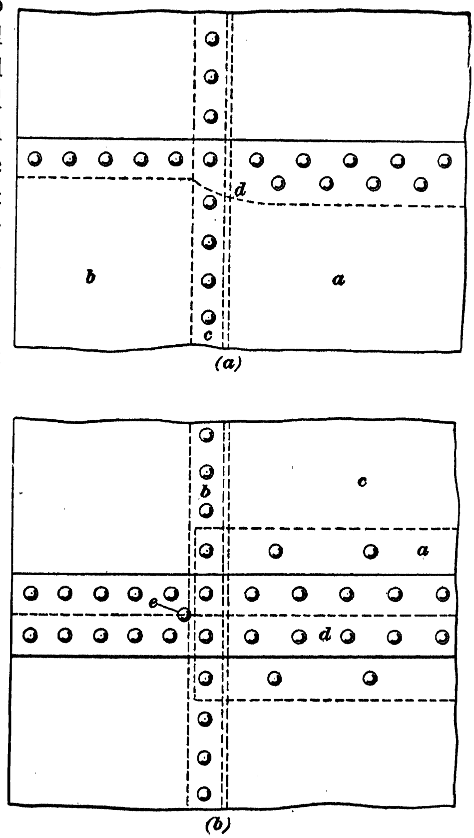
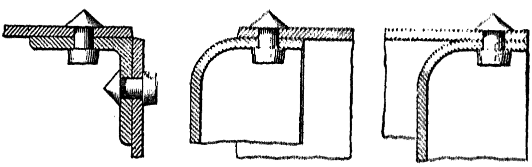


FIG. 20

19. Arrangement of Smokebox Joints.—In the locomotive type of boiler, which always has a smokebox, and in the horizontal return-tubular boiler, which may have one, the smokebox may be a separate course, or the first course may be extended, serving for both the smokebox and the first course. The first mentioned construction is customary for large boilers, and the second one for small boilers. In boilers having double-riveted longitudinal lap joints and the first course and smokebox made of one sheet, there is no need of double-riveting the longitudinal joint of the smokebox, as it is not subject to pressure. The usual method of arranging the seams is shown in Fig. 20 (*a*). In this illustration, part of the first course is shown at *a*; the smokebox end of the sheet, at *b*; and the front flue sheet, or round head, which is backed in, at *c*. Because the smokebox is single-riveted while the shell sheet is double-riveted, the shell sheet is cut away as shown. The inside of the shell plate is scarfed at *d* in order that a tight joint can be made between it and the head *c*.

20. In a boiler having the first course and the smokebox made of one sheet and a longitudinal double-riveted double-strap butt joint, it is the usual practice to scarf the inner butt strap *a*, Fig. 20 (*b*), and insert the scarfed end between the flanged head *b* and the shell sheet *c*. The outer butt strap *d* is made long enough to reach to the end of the smokebox and is single-riveted, as shown. A stop-rivet *e* is placed at the edge of the flange of the front head.



(*a*) (*b*) (*c*)

FIG. 21

21. Methods of Making Angular Connections.—There are various ways of making angular connections in structural and boiler work. Some of the methods are illustrated in Fig. 21. For structural work, such as tanks, breechings, and bases for

boilers, the plates can be readily joined by riveting them to an angle iron, as shown in (*a*). For boiler work, in which the ends of the shells are closed in, it is the usual practice to use flanged heads, as shown in (*b*) and (*c*). The head in (*b*) is turned with the flange inwards and in (*c*) it faces outwards.

Two ways of connecting an internal furnace to a tube-sheet are shown in Fig. 22 (*a*) and (*b*). To make the connection shown in (*a*), the tube-sheet *a* must have a flange *b* turned *inwards*. The furnace *c* is then brought flush with the outer surface of the tube-sheet and riveted to the flange. The connection shown in (*b*) is made by turning the flange *a* outwards and riveting it to the furnace *b*, which is set flush with the outer edge of the flange. This method requires a longer shell *b*, but it permits the riveting to be done on the outside.

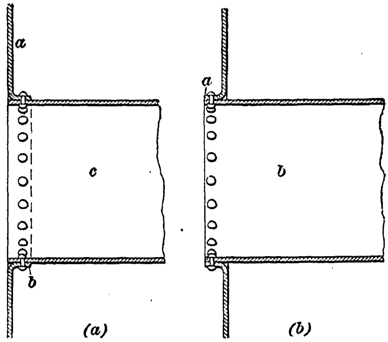


FIG. 22

ARRANGEMENT OF FIREBOX JOINTS

22. Fire-Door and Mud-Ring Connections.—A method of forming the fire-door hole for the furnace of a vertical boiler is shown in Fig. 23, the same method being also used to some extent with the smaller types of locomotive boilers used for stationary purposes. The door ring *a* is usually a steel casting or a wrought-iron ring placed between the shell plate and the furnace plate, and riveted with a single row of rivets. An objection to placing the door ring in this way is that it is so rigid that it prevents free expansion of the furnace plate, which causes leaks within a short time along the calking edge *b* and at the inner rivet heads *c*. The bottom of the water space may be closed by forming an ogee flange *d* on the furnace sheet and then riveting it to the shell. This construction, however, is not adopted when the furnace plate is rela-

tively thin or the water space at the bottom very large, because the thickness of the sheet will be reduced considerably by the operation of flanging.

23. In locomotive-type boilers, the fire-door hole is usually constructed as shown in Fig. 24. The door sheet *a* of the furnace is flanged outwards and the back head *b* is flanged inwards,

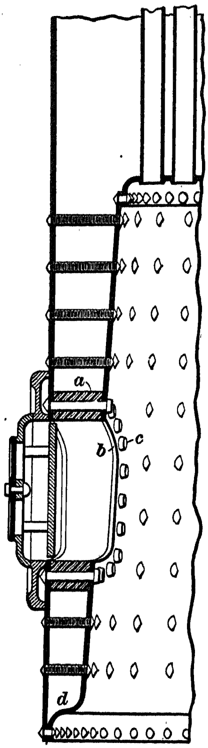


FIG. 23

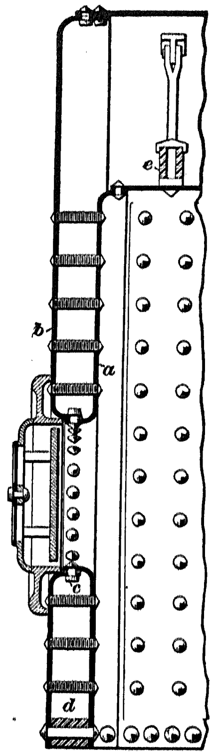


FIG. 24

the two flanges being united by a row of rivets *c*. The bottom of the water leg must not be closed by flanging the furnace sheets, as this would prevent the holding on and driving of the rivets *c*. It is closed by placing a mud-ring *d* between the furnace sheets and the outer plates and securing the ring to the sheets with rivets. The mud-ring is usually made of wrought iron, although cast-steel rings are extensively used.

24. Experience has shown that in fire-door holes constructed as shown in Fig. 24 the inner sheet will sooner or later crack from the calking edge to the rivet holes *c*, and also in the curved part of the flange. The inner, or furnace, sheet *a* is highly heated when the boiler is in use, but owing to the rigidity of the flange and the joint at the fire-door hole, aided by the adjoining staybolts, the flanged part of the fire-door of the furnace sheet cannot expand as freely as the other parts of the sheet, and stresses are thus set up in this part. Every time the fire-door is opened the stresses are intensified by the inrush of cold air that cools the joint and causes contraction. The repeated bending of the material under these stresses will ultimately cause rupture at one or more places. A collection of sediment on top of the fire-door hole leads to overheating and increases the danger of cracking the plates.

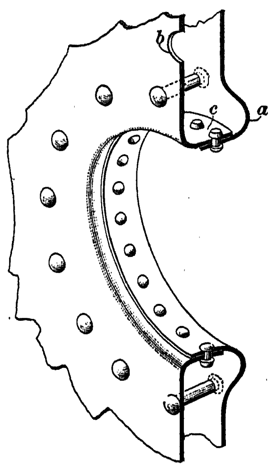


FIG. 25

25. To lessen the danger of cracking at the fire-door holes, the construction illustrated in Fig. 25 has been devised. The end sheet of the furnace is flanged to an ogee curve having radii as shown at *a*; for this reason, the furnace sheet is rendered rather flexible at the fire-door hole. A good-sized washout hole *b* placed directly over the fire-door permits the ready removal of foreign matter that collects around the top of the door flanges at *c*. In Fig. 26 (*a*) to (*c*) are shown several other forms of construction for door-hole openings.

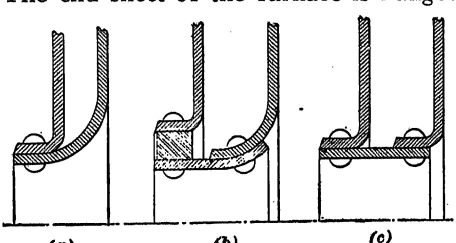


FIG. 26

26. Connecting Sheets to Mud-Rings.—In large locomotive-type boilers the bottom of the water leg is closed by a wrought-iron or steel mud-ring. In modern practice, the ring is made of sufficient depth to project about ½ inch below the lower edge *a*, Fig. 27, of the furnace and water-leg sheets, thus permitting the edges to be calked from the sides. If the mud-ring does not project below the lower edges of the sheets, leaky calking edges are calked with great difficulty, especially if the boiler is standing on a frame or foundation. To prevent the mud-ring from cracking at the corners, it is good practice to provide a boss *b* at each corner. The extra metal in the boss will counteract the weakening effect of the holes drilled for the *corner bolts,* which are bolts used to fasten the sheets to

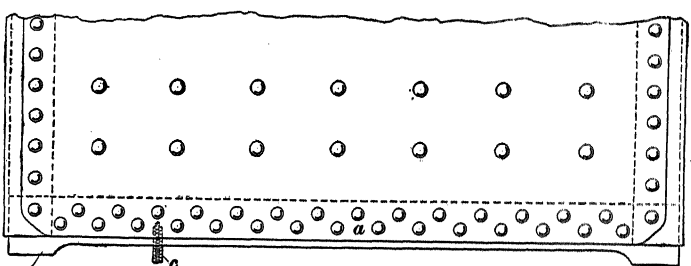


FIG. 27

the mud-ring at the corners. Mud-rings for boilers carrying medium pressures are generally single-riveted; for high-pressure boilers, double zigzag riveting is considered good practice.

27. When studs are to be screwed into mud-rings for attaching an ash-pan or for a similar purpose, the studs must be so located as to clear the rivets. In a single-riveted mud-ring, the studs should be placed midway between rivets; in a double-riveted mud-ring, they should be placed directly beneath a rivet of the upper row, as shown at *c*, Fig. 27.

28. In modern practice, mud-rings are machined both inside and outside, thus eliminating the expensive and difficult work required to make the sheets fit metal to metal over an unfinished or rough mud-ring. The corners of mud-rings should be shaped as illustrated in the plan view, Fig. 28 (*a*). This con-

struction makes the flange of the furnace sheet a and the outside firebox sheet b lie flat. The furnace side sheet c and the boiler head d are scarfed to go under the sheets a and b. If the corners of the mud-ring are shaped as shown in (b), the

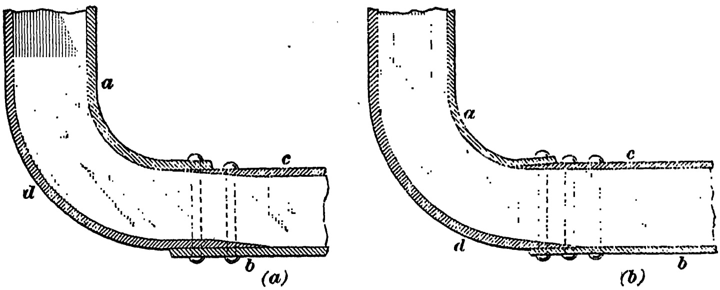


FIG. 28

flanged furnace sheet a will have to be bent inwards to go over the scarfing of the furnace side sheet c, and the outer firebox sheet b will have to be bent outwards to go over the scarfing of the boiler head d. Such construction is not only expensive and unsightly, but it also requires three lengths of rivets at the joints, whereas only two lengths of rivets will be required if the corner is laid out as shown in (a).

29. The outside sheets of firebox boilers are fastened to the corners of the mud-rings by threaded corner bolts, the number and arrangement at each corner depending on the radius of the corner and whether the sheets are single-riveted or double-riveted to the mud-ring. A usual arrangement of corner bolts is shown in Fig. 29, in which the boiler head is shown at a, the outer firebox sheet at b, the flanged furnace sheet at c, and the furnace side sheet at d. The sheets a and c are first laid against the mud-ring, after which the holes

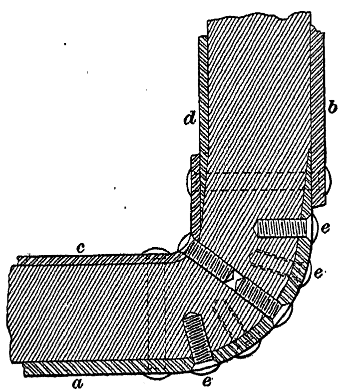
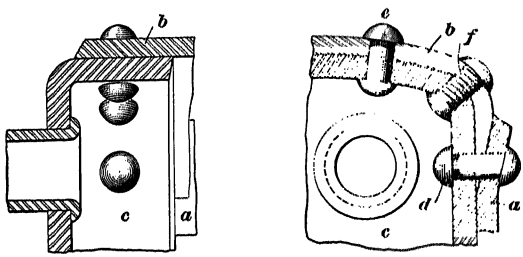


FIG. 29

for the corner bolts *e* are drilled through the sheets *a* and *c* into the mud-ring. The holes are then tapped, and enlarged or countersunk in the plates *a* and *c*, so that the heads of the corner bolts will be similar to oval countersunk rivet heads. Instead of using corner bolts with oval heads, some mechanics thread a rod and screw it into the mud-ring. This rod is then cut off, sufficient material being left to form a head, and the projecting ends are riveted over, thus filling the countersunk holes in the plates *a* and *c*. The edges of the bolt heads are always calked down to the sheet. In the illustration, corner bolts are used at the corner, but very often rivets are used at this point.

30. In Fig. 30 (*a*) is illustrated a longitudinal section and in (*b*) a cross-section of a firebox corner, showing the con-



(*a*) (*b*)

FIG. 30

nection between the side sheet *a*, the crown sheet *b*, and the tube-sheet *c*. If the tube-sheet is flanged to a very small radius in the corner, it is very difficult to drive a rivet properly midway between the rivets *d* and *e* in (*b*), that is, directly in the corner. The usual practice is to drill and tap a hole at this point, generally using a tap $\frac{3}{4}$ inch in diameter and having twelve threads per inch. A plug *f* is then screwed tightly into the tapped hole and its ends are riveted over and calked.

31. Fire-Cracks in Joints.—It has been found by experience that in firebox boilers the furnace side of the furnace sheets is liable to crack at the joints from the rivet holes outwards toward the edge of the plate, such cracks being termed *fire-cracks*. The lap joints are kept relatively cool on the

water side, but the fire side of the lap, especially with thick plates, becomes so hot as to set up stresses that ultimately result in cracks. To reduce the liability that fire-cracks will occur, it is the practice to bevel the furnace side of the lap from *a*, Fig. 31, to the edge *b*, countersink the rivet holes, and drive oval countersunk rivets *c*. The thinning of the material assists the water on the water side in keeping the furnace side of the lap cool, and does not reduce the strength of the joint, as the pressure tending to rupture the joint acts in the direction of the arrow.

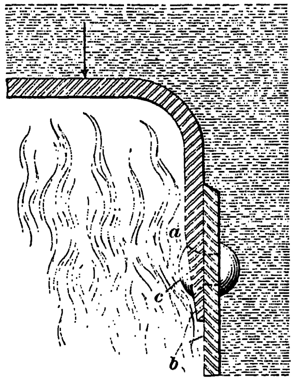


FIG. 31

32. In an externally fired boiler of the horizontal return-tubular or flue type, part of the girth seam is exposed to the flames and fire-cracks may occur on the fire side of the seam. As the internal pressure, indicated by the arrows in Fig. 32 (*a*) and (*b*) tends to pull the lap apart and to crush or shear out the metal between the rivet holes and the edge of the plate, the lap should not be beveled as shown in Fig. 31, because this would materially weaken the joint. A common construction at the girth seams is shown in Fig. 32 (*a*), the rivet having an oval head on the fire side. If, however, the rivet is made with a countersunk head on the fire side, as shown in (*b*), there

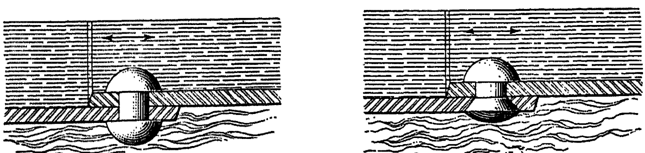


FIG. 32

will be less material at the joint without greatly weakening the plate; consequently, the water will tend to maintain a more nearly uniform temperature at the lap, thereby reducing the liability of the occurrence of fire-cracks.

HEADS OF BOILERS AND DRUMS

FLAT HEADS

33. The tube-sheets of locomotive, vertical, flue, and horizontal return-tubular boilers are flat circular plates with flanges at the outer edges, by which they are riveted to the shells of the boilers. As a general rule, the tube-sheet, or head, is inserted in the manner shown in Fig. 21 (*b*); that is, the edge of the flange is inside the shell and the convex part

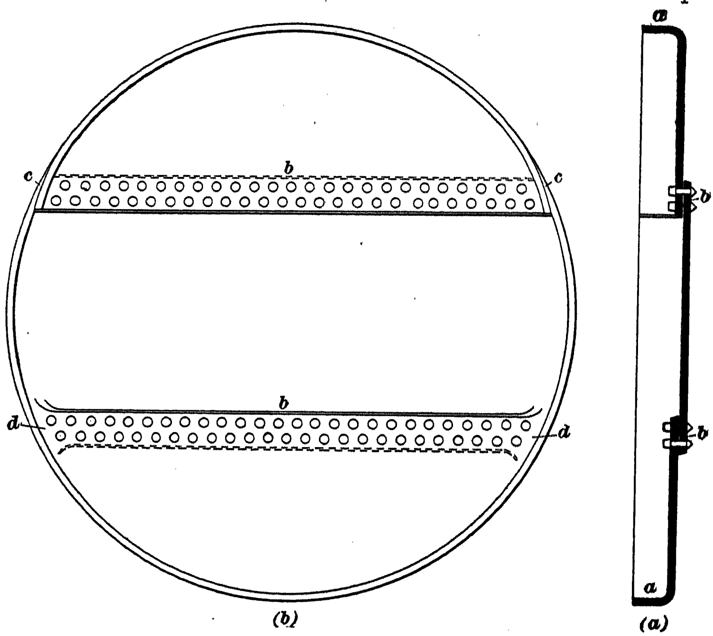


FIG. 33

of the flange faces outwards. However, it is not uncommon for the head to be backed in, as in (*c*), in which case the flat part of the head lies well within the outer end of the shell. As flat surfaces are not self-supporting when subjected to pressure, the flat heads of boilers are braced by diagonal stays above the tubes and by through stays, from head to head, below the tubes and on each side of the manhole

34. It is customary to make the head of a boiler of a single piece of plate; but if the boiler is of great diameter, the head must be built up of two or three sections riveted together. For example, Fig. 33 (*a*) and (*b*) shows the back head of a marine boiler of the Scotch type, which is of such diameter that it is made of three plates that are flanged separately, as at *a*, and then riveted together. After the flanging has been done, the sections are fitted together and the positions of the rivet holes *b* are marked. A few rivet holes are drilled and

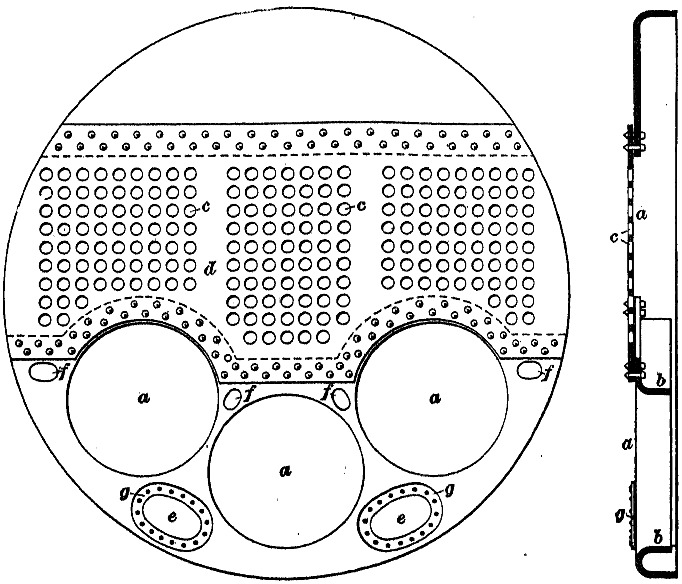


FIG. 34

bolts are inserted to hold the sections together in their correct relative positions, after which the remaining holes are drilled. If the flanges of adjoining sections are lapped, as at *c*, the outer flange is scarfed and the inner one set in a trifle, as shown. In some cases, however, the flanges are welded together, as at *d*.

The front head of a Scotch boiler having three openings *a* for the furnace connection is shown in Fig. 34. The openings are cut in the lower sheet and the flange required for riveting

the furnaces to the head is turned in as shown at *b* in the sectional view. The tube holes *c* are drilled in the section *d* and the manholes *e* and handhole openings *f* are cut in the lower plate. The manhole openings may be flanged in, in the same manner as the furnace openings, or they may be reinforced by riveting wrought-iron or steel rings to the head, as shown at *g*.

BUMPED HEADS

35. Heads that are bent to the convex and concave forms shown in the sectional views, Fig. 35 (*a*) and (*b*), are called *bumped heads*, or *dished heads*. They are used in plain cylindrical boilers, steam drums, mud-drums, oil tanks, air reservoirs, etc. The head in (*a*) is convex outwards and is therefore a convex head, whereas the head in (*b*) is concave outwards and is a concave head. A dished head backed in, as shown in (*b*), is used only in cases where there is in the shell no opening large enough to permit the driving of the rivets.

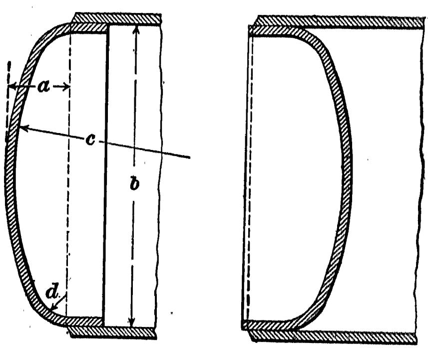
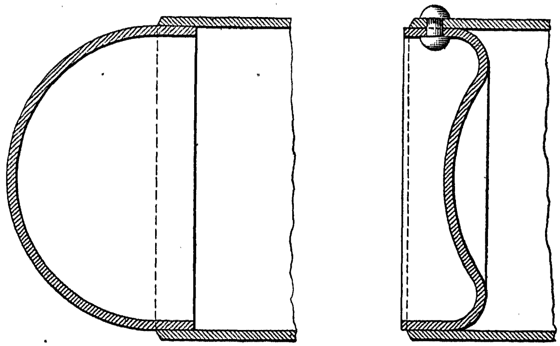


FIG. 35

Dished heads with the pressure on the convex side of the head, as in (*b*), are not so strong to resist pressure as heads having the pressure on the concave side, as in (*a*). The A. S. M. E. Boiler Code provides that a bumped head having the pressure against the convex face, as in (*b*), shall be allowed a maximum working pressure of only 60 per cent. of that for a bumped head of the same dimensions but having the pressure against the concave face, as in (*a*).

The depth *a* of the dished part of the head depends on the inside diameter *b* of the shell to which the head is riveted. The curve of the dished head has a radius *c* equal to the inside diameter *b* of the shell. The corner radius *d* is not less than

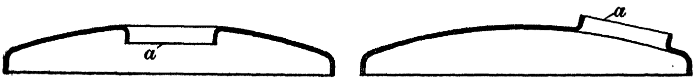
$1\frac{1}{2}$ inches nor more than 4 inches. A bumped head arranged as in (*a*) is self-supporting for certain working pressures, since the head is a section or segment of a sphere and is already curved to the shape it would naturally assume under pressure.



(*a*) (*b*)

FIG. 36

36. The strongest form of dished head is the *hemispherical head,* Fig. 36 (*a*), which is used in some types of cylindrical boilers built in England. The form of head illustrated in Fig. 36 (*b*) is used in tank work; the objections to it are that



(*a*) FIG. 37 (*b*)

there is difficulty in shaping it and in maintaining tight rivets at its joint with the shell. Bumped heads may have manhole openings flanged inwards or outwards, as shown in Fig. 37 (*a*) and (*b*), respectively. These flanged openings are known as plain flanged manholes. In the flanging process, the metal is stretched along the face *a* of the flange, and this condition is more pronounced in light-plate than in heavy-plate flanging. To compensate for the reduction in plate thickness and to give greater stiffness and strength to the flange *a*, a steel band or ring *b* may be shrunk on the flange and secured to it by studs *c*, as shown in Fig. 38.

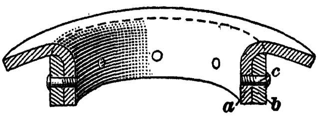


FIG. 38

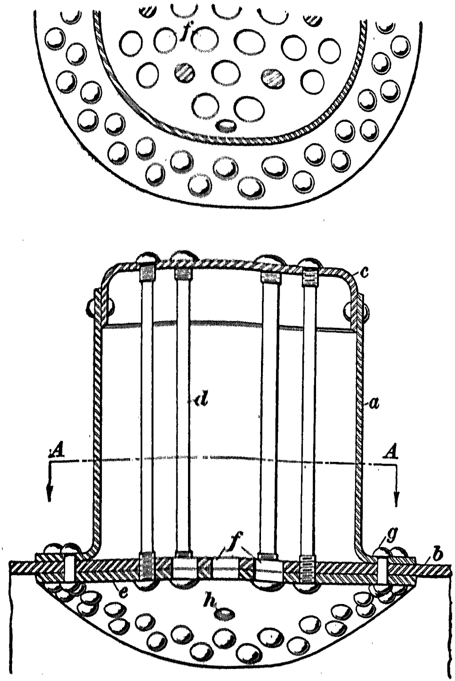
DOMES AND DRUMS

STEAM DOMES

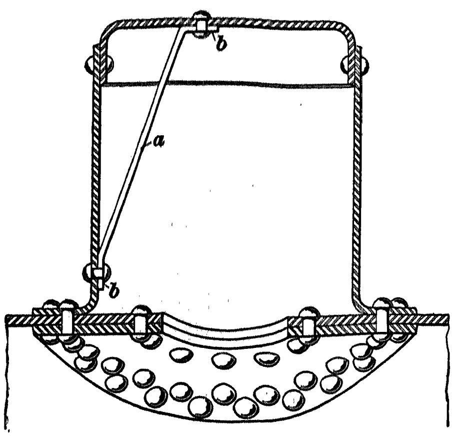
37. Domes on Stationary Boilers.—In small fire-tube boilers of the locomotive, horizontal return-tubular, and flue types, domes of the form shown in Fig. 39 are very often attached at the top of the boiler shell. A dome is placed on a boiler for the purpose of increasing the steam space and also for the purpose of obtaining drier steam, the supposition being that the steam will be drier on account of its being farther removed from the water. The dome shell *a* in (*a*) is flanged and riveted to the boiler shell *b*. A flanged head *c* closes the dome at the top. To support the flat surface of the head, either of the methods of bracing shown in (*a*) and (*b*) may be employed. In (*a*) the stays *d* are threaded and screwed into the boiler plate *b*, the dome liner *e*, and the head *c*, and the ends are then headed over. The method of bracing shown in (*b*) consists of using diagonal braces *a* having at each end a palm or foot *b* parallel to the surface to which it is riveted.

38. Communication between the steam space and the dome may be provided by cutting a number of small holes *f*, Fig. 39 (*a*), through the shell plate below the dome; or, a single opening may be cut in the boiler shell, as in (*b*). In either case the total cross-sectional area of the opening or openings should be greater than the area of the steam outlet. The openings in the shell reduce its strength, and to compensate for its weakened condition the practice is to rivet a reinforcing ring, or liner, around the dome connection as at *e* in (*a*). The rivets *g* that hold the dome to the shell pass through both the liner and the shell. Drain holes *h* are also provided in the boiler shell near the lowest point of the junction of the base of the dome and the boiler shell. Water that collects from the condensation of steam flows back through these holes into the boiler.

An approximate rule for determining the size and height of a steam dome is to make its diameter equal to one-half the



(a)



(b)

FIG. 39

diameter of the boiler, and its height equal to nine-sixteenths of the diameter of the boiler.

39. Locomotive Boiler Domes.—The domes of locomotive boilers are usually made of heavier plate than those of stationary boilers. The principal types of locomotive domes are shown in Figs. 40 and 41. The three-piece dome shown in Fig. 40, which is quite common, is made with a heavy collar or base *a*, from $\frac{3}{4}$ to 1 inch in thickness, having two flanges of about the same length. One of these flanges is riveted to the boiler shell and the other to the dome shell *b*. The shell *b* is made of lighter plate than the dome base and is closed at the top by a flanged flat head *c*. Domes are also formed in one piece, as illustrated in Fig. 41. This method of construction produces the strongest type of dome and offsets the need of several riveted joints. Such domes are pressed out of heavy plate, from $\frac{3}{4}$ to 1 inch thick. It will be noticed in (*a*) that the dome has a slight taper, being 29 inches in diameter at the top and 30 inches at the base. Owing to the heavy plate thickness the right-angle flanges are made with a large radius *a* of $4\frac{1}{2}$ inches, and a radius *b* of 3 inches is used for the larger flange angle, as shown in (*b*).

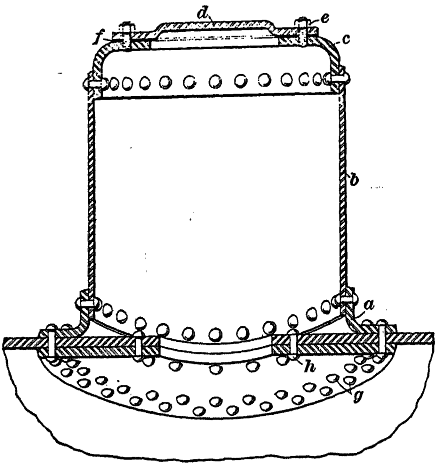
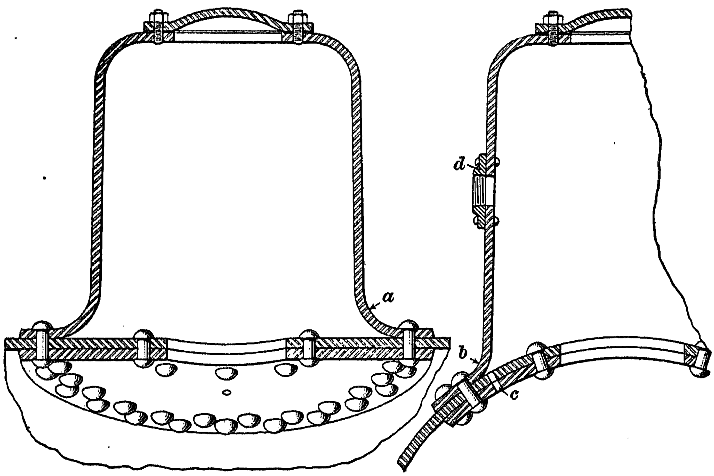


FIG. 40

40. In boilers of the locomotive type it is usually necessary to have a large opening in the dome head to permit the erection of the steam pipe and the throttle valve. Such an opening is circular in form and covered with a pressed-steel cap *d*, Fig. 40, which is fastened to the dome head by studs and nuts *e*. The upper surface of the dome head and the

bottom face of the cap *d* are faced or machined so that when the cap is bolted down on the copper gasket *f* a steam-tight joint will be obtained. The dome cap may be made in several ways. Sometimes it is straight, as shown, and sometimes it is dished, as indicated in Fig. 41. The latter form adds strength to the cap. To reinforce the opening in the shell, a steel reinforcing ring is riveted to the shell and the dome, as in



(a) (b)

FIG. 41

Fig. 40, with a double outer row of rivets *g* and a single inner row of rivets *h*. Drip holes, as at *c*, Fig. 41 (*b*), are provided to drain away water that collects at the base of the dome. To attach the safety valve and the whistle to the dome, threaded flanges like the one shown at *d* are riveted to the side of the dome shell.

41. The Boiler Code of the A. S. M. E. requires that the longitudinal joint of a dome 24 inches or more in diameter shall be of butt and double-strap construction irrespective of pressure. When the maximum allowable pressure exceeds 100 pounds per square inch, the flange of a dome 24 inches or over in diameter shall be double-riveted to the shell. For domes less than 24 inches in diameter the longitudinal seam may be

of the lap-joint type, and the flange may be single-riveted to the boiler, provided that a factor of safety of not less than 8 is used in determining the allowable working pressure on the dome.

The corner radius of the flange, measured on the inside of the plate, shall equal at least twice the thickness of the plate, for plates 1 inch thick or less, and at least three times the plate thickness for plates over 1 inch in thickness.

The dome may be located on the barrel or over the firebox on traction, portable, and stationary boilers of the locomotive type, up to and including a shell diameter of 48 inches. For larger boiler diameters, the dome shall be located on the shell of the boiler.

42. Dry Pipe.—The use of steam domes is giving way to the practice of installing larger boilers with the required steam space and placing inside a fitting known as a *dry pipe*. It is usually made as shown in Fig. 42. The central section *a* is a tee into which are screwed the pipes *l* and *c* and the nipple *d*. The pipes *b* and *c* are slotted along the top, or else holes are drilled through them, as shown. The combined area of these openings should be larger than the cross-sectional area of the steam outlet *e*. It is usually one-third greater than the area of the steam outlet.

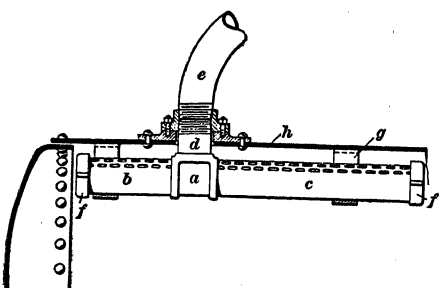


FIG. 42

The ends of the dry pipe are closed with caps *f* and at the bottom of the pipe a drip hole is drilled to allow water to drain out. The dry pipe should be connected at the highest point in the steam space of the boiler, and in such a manner that the steam can enter it through the perforations at the top. It is supported at the ends by iron straps *g* riveted to the drum *h*.

STEAM DRUM

43. Purpose and Arrangement of Steam Drums.—The steam drum is a cylindrical vessel often attached at the top of a fire-tube boiler to increase the steam space, thus serving as a substitute for the steam dome. One form of steam drum attached to a fire-tube boiler is shown in Fig. 43. The drum is composed of two shell courses *a*, closed by two dished heads *b*, and is attached to the top of the shell *c* by two flanged steel nozzles *d*. There is some objection to this construction on account of unequal expansion and contraction stresses that arise in the boiler shell and drum, which may cause the nozzle seams to leak. To overcome this condition, one nozzle is sometimes used. To provide an entrance to the steam drum for cleaning, inspection, and repairs, a manhole *e* is placed in one of the dished heads. The steam outlet is connected at the top of the drum, as shown at *f*, and the safety valve is attached at *g*. The feedwater enters through the pipe at the bottom of the drum, passes down through the front nozzle and deposits much of its sludge in the pan beneath the nozzle.

44. A steam drum is not generally used on a single boiler, but it is often used if a number of boilers are set in a battery, the steam drum being connected directly to the top of each boiler. It is then placed transversely, and is usually connected to the boilers by long curved pipes, to allow for the expansion and contraction of the header. In most designs of water-tube boilers steam drums are used; however, they are partly filled with water. If each boiler in a battery has an independent furnace, there should be a stop-valve between each boiler and the steam drum, to allow each boiler to be cut out of service; if the battery of boilers has one furnace common to all, no stop-valve should ever be placed in the nozzle or pipe between each boiler and the drum. A single steam drum, when it is applied to a battery of boilers, is often called a *header*. If a header is applied to a battery of boilers that has a furnace common to all the boilers, one safety valve is sufficient for the entire battery; but if a header is connected with a battery of boilers, each of which has its own furnace and

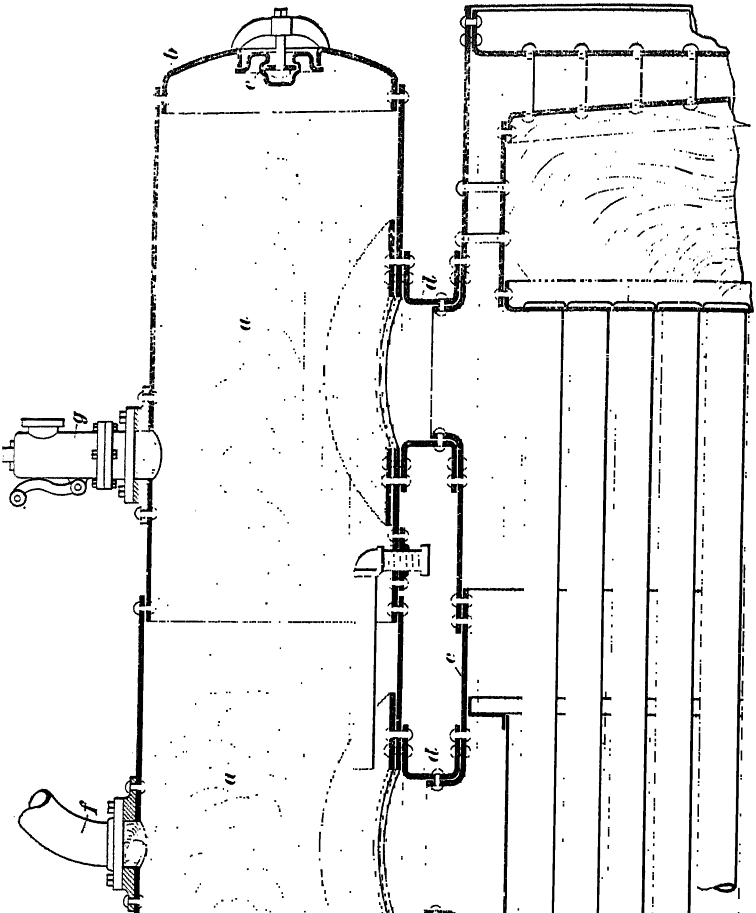


Fig 43

stop-valve, an independent safety valve, attached directly to the shell, should be placed on each boiler of the battery.

45. Size and Strength of Steam Drums.—When a steam drum is used for a single boiler, its diameter may be made equal to one-half the diameter of the boiler, and its length equal to the diameter of the boiler. When one steam drum is common to several boilers, its diameter is usually made equal to half the diameter of one of the boilers, and its length equal to the horizontal outside-to-outside measurement over the several boiler shells.

The strength of steam drums may be determined by the rules governing the strength of boiler shells. They require just as rigid inspection as the boiler itself.

MUD-DRUMS AND BLOW-OFFS

46. Mud-Drums.—Cylindrical mud-drums made of steel in the same manner as the steam drum in Fig. 43 are sometimes used with stationary boilers of the fire-tube type. In such cases the drum is attached to the bottom of the boiler to provide a suitable place for the collection of mud and sediment held in suspension in the feedwater. The feedwater is sometimes introduced into the drum, from which it passes into the boiler. In shell boilers the mud-drum is located at the end farthest from the furnace, as shown in Fig. 44. The drum *a* rests on a standard *b* and is connected to the boiler shell by flanged nozzles *c*. A

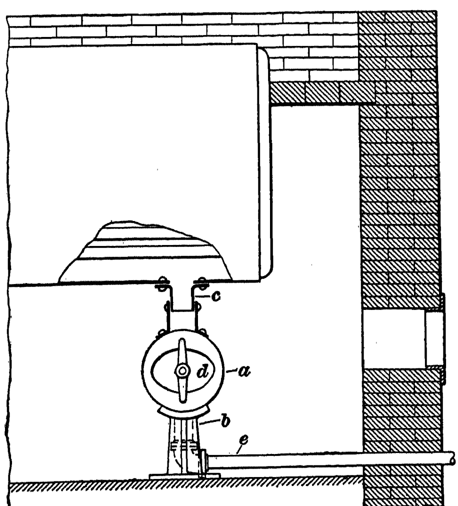


FIG. 44

manhole *d* is provided in the end of the drum for cleaning and repairs, and blow-off piping *e* is connected at the bottom of the drum for blowing out the mud and other sediment. A protecting wall of brick may be built in front of the drum when it is placed inside the boiler setting, so that it may not be directly exposed to the fire temperature. The difficulty arising in the use of such drums is that the mud deposited tends to become baked and hard, and unless the drum is frequently cleaned, there is danger of its becoming entirely clogged. In some types of water-tube boilers one or more cylindrical drums form water-drums and mud-drums, serving primarily to distribute the feedwater to the tubes and incidentally to collect mud and other feedwater sediment.

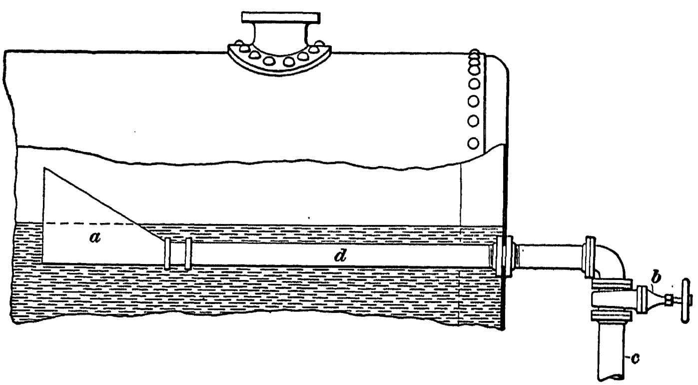


FIG. 45

47. Surface Blow-Off.—The surface blow-off *a*, Fig. 45, is a sheet-metal funnel or scoop so arranged that its outlet is submerged at the lowest water level and its upper edge at the highest water level. It should be placed at about one-third of the length of the boiler from the rear head. It is installed for the purpose of removing the scum and other impurities that rise to the surface of the water. When the valve *b* is opened, the steam pressure forces the scum and some water to flow out through the blow-off piping *c* which is usually connected to a blow-off tank. If the scum is not removed, it will prove detrimental to the operation of the boiler, for it will

prevent the steam bubbles from escaping freely, and some of the scum may be carried off with the steam into the power-plant auxiliaries, affecting their operation. Sometimes, the funnel *a* is fitted with floats and the pipe *d* is swiveled, so that the funnel will follow the rise and fall of the water level in the boiler.

48. Blow-Off Tank.—A blow-off tank is a cylindrical vessel made of boiler plate, as shown in Fig. 46, the shell *a* being riveted to dished heads *b*. The top head contains a manhole *c* to provide entrance into the tank for cleaning. A vent pipe *d* is provided at the top so as to prevent the accumulation of excessive pressure in the vessel. The blow-off pipe leading from the boiler is connected at *e* and the water is drained out through the pipes *f* and *g*. The purpose of the blow-off tank is to entrap the hot water blown off from the boiler, so that it will cool before being discharged into the sewer. By this arrangement the danger of damaging the sewer by hot water is avoided. The blow-off tank is provided with a siphon breaker *h* to prevent a siphoning action through the pipe *g*, as it is desired to keep the tank filled with water to the level of the overflow pipe *i*.

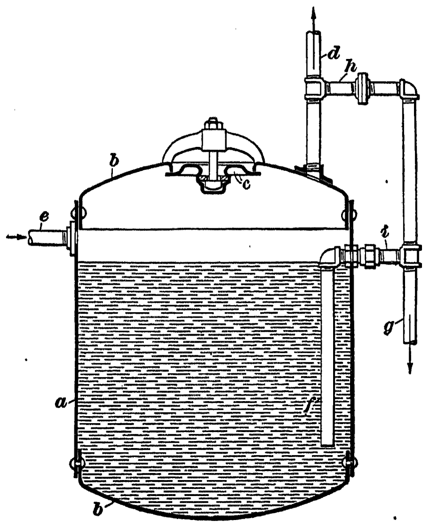


FIG. 46

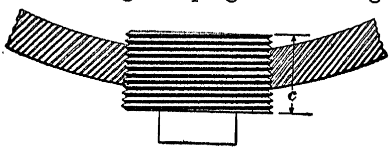
OPENINGS IN BOILERS

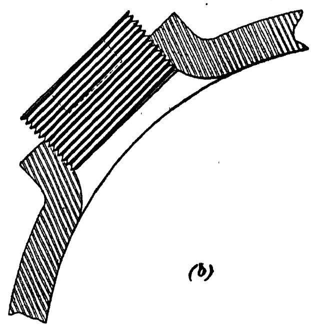
STEAM, WATER, AND WASHOUT OPENINGS

49. Classes of Openings.—In all types of boilers, a number of holes, or openings, must be cut through the boiler shells, heads, domes, or drums for the outlet of steam, for the inlet and outlet of water, and for the purposes of cleaning, inspecting, and repairing. It is customary to designate each opening in accordance with the purpose it serves; thus, the hole through which the feedwater is admitted is the feedwater hole; the hole into which a gauge cock is screwed is the gauge-cock hole. An opening cut into a boiler for the purpose of washing out foreign matter and incidentally permitting inspection is an inspection hole, a washout hole, or a handhole, the last term being preferably used when the hole is large enough to admit the hand. When a hole is large enough to permit the passage of a man's body it is a manhole. One or more manholes should be placed in each boiler that is large enough to permit this, one manhole being placed in the front head and another in the boiler shell. Sometimes a manhole is placed in the rear head instead of in the boiler shell.

50. Washout Holes and Plugs.—In locomotive-type boilers, washout holes are placed in convenient places in the water legs below and above the tubes, for washing out mud and other sediment that collects in the boiler. These openings are threaded and plugged. Round brass plugs for closing washout holes are called *washout plugs*. They generally have twelve threads per inch, cut on a taper of $\frac{3}{4}$ inch per foot. Two types of washout plugs are used, differing only in the manner of receiving the wrench for screwing them in or out. The form shown in Fig. 47 (*a*) is a male plug, and is the one most generally used; the form shown in (*b*) is a female plug, and is used only where the projecting square shank of the male plug is not permissible. The body of the female plug is recessed to receive the wrench by which it is screwed into place.

51. Washout plugs are generally screwed directly into the sheet, as shown in Fig. 47 (*a*), but when placed in a part of the sheet curved to a very small radius, the sheet is flanged out and the plug is screwed into the flange, as shown in (*b*). The flanging of the sheet for a washout plug is necessary in such a case in order to provide a sufficient number of perfect threads for holding the plug and making





(a) (b)

FIG. 47

it tight. The length *c* of the threaded part of the plug, as shown in (*a*), should be sufficient to give, when the plug has been screwed home, at least two threads inside and three or four threads outside the sheet into which it is screwed.

52. Handhole Openings and Cover-Plates.—Handhole openings may be made circular in form, but they are generally elliptical. The common sizes are 3 in. by 5 in., 4 in. by 6 in., 5 in. by 7 in., 6 in. by 8 in., and 6 in. by 10 in. They are made to fit either flat or bent plates. For stationary boilers two general types of handholes are used, one of which is shown in Fig. 48. It consists of a cast-iron or steel cover-plate *a* and a *yoke,* or *crab,* *b* of steel or cast iron. The bolt *c* passes through the cover-plate, which has a countersunk head riveted over at the end *d*. To produce a steam-tight joint, a gasket *e* is placed between the boiler plate and the cover-plate; then, by tightening the nut *f*, the cover-plate is brought to bear against the gasket and plate. The gasket should be made of heat-

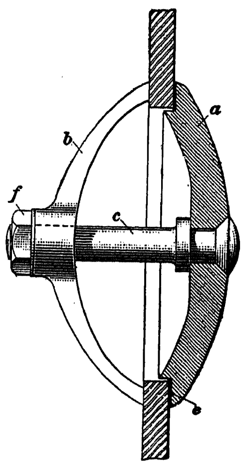


FIG. 48

resisting and waterproof material when used for steam connections. Various compositions of rubber and asbestos are employed for this purpose. Before being placed in position the gasket should be coated on both sides with graphite in

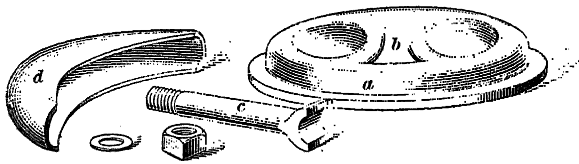


FIG. 49

order to prevent it from sticking to the metal when the cover is removed. It may then be used a number of times. The different parts of an elliptical pressed-steel handhole cover-plate are shown in Fig. 49. The plate *a* is formed under hydraulic pressure and the two curved transverse ribs provide

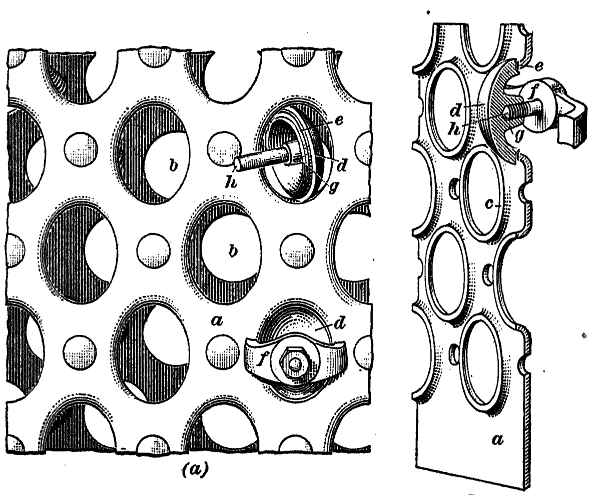


FIG. 50

a socket *b* into which is slipped the head of the bolt *c*. The yoke *d* is also of pressed steel, and the combination of plate and yoke gives a stronger and lighter form of handhole cover arrangement than the cast-iron or steel type.

53. Handholes for water-tube boilers are made either circular or elliptical. When the circular form is used, it is necessary to have a number of large elliptical handholes through which the covers for the adjoining circular handholes can be installed and removed. In Fig. 50 is illustrated the type of handhole equipment used in the Edge Moor water-tube boiler. The outer plate *a* opposite the point where each tube *b* enters the inner tube-sheet is pressed to form a raised elliptical seat *c*, as shown in the rear view of the plate *a*, given in (*b*). The edges of these seats are machined to provide smooth faces against which the handhole plates *d* can be drawn to produce steam-tight joints. A gasket *e* is placed between the plate and the handhole cover. The yoke *f* and the plate *d* are drop forgings and the plate is formed with a boss *g* that is threaded to receive the stud *h*.

54. In some makes of water-tube boilers, a special form of metal-to-metal handhole construction is used. It is known as the *Key handhole*, and is shown in Fig. 51. The handhole cover *a* is a plug or cap with tapering sides that match the taper of the opening cut in the boiler plate *b*. The plug is inserted from the inside, opposite the end of the tube *c*, and

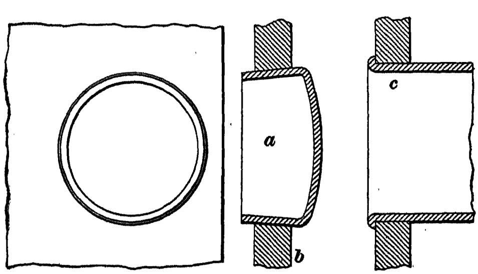


FIG. 51

is pulled into place from the outside by a special tool made for the purpose. The boiler pressure against the head of the plug forces it to its seat. Because of its shape the plug is stronger than the ordinary handhole cover. It eliminates the necessity of a yoke, bolt, and nut, and also avoids the use of a gasket, which very often blows out and causes trouble. As the head

of the plug is circular, it cannot be put in from the outside through the circular opening that it closes. Instead, *master handholes,* as shown in Fig. 52, are provided in the bottom of the headers, through which the tapered plug is inserted and

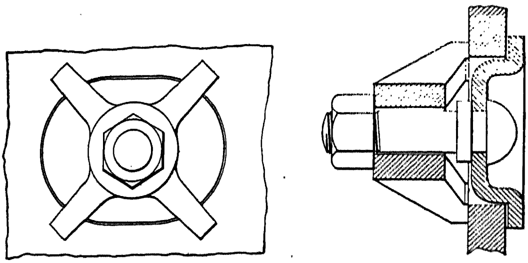


FIG. 52

then placed in the circular opening. When a handhole opening exceeds 6 inches in any dimension, the metal around the opening must be reinforced by a steel ring or liner.

MANHOLES

55. In general, the construction of a manhole and its cover does not differ materially from that of a handhole and its cover, except that the former is larger, being 10 in. by 14 in., 11 in. by 15 in., or 12 in. by 16 in. The usual size is 11 inches by 15 inches. A manhole should be cut in a boiler shell with the long diameter, or long axis, parallel to the girth seam,

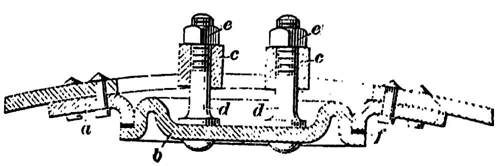


FIG. 53

because the stress per inch of girth seam is only half as great as the stress per inch of longitudinal seam. As the shell is materially weakened by cutting such a large hole, it is necessary to reinforce the plate around the manhole opening. The general practice in reinforcing manholes in shell boilers is to

rivet a reinforcing plate or a flanged ring *a*, Fig. 53, on the inside of the shell plate. The cover-plate *b* is held in position by two crabs *c* and the bolts *d* and nuts *e*. A gasket *f* is employed to obtain a steam-tight joint. The formation of the saddle or reinforcing ring is illustrated in Fig. 54; the plan view indicates the shape of the elliptical opening *a* and the width of the flange *b*, and the sections show the form of the flanges *b* and *d*. The flange *b* is turned to fit the curvature of the shell, and the flange *d* is straight across the face *e* to furnish a seat for the cover.

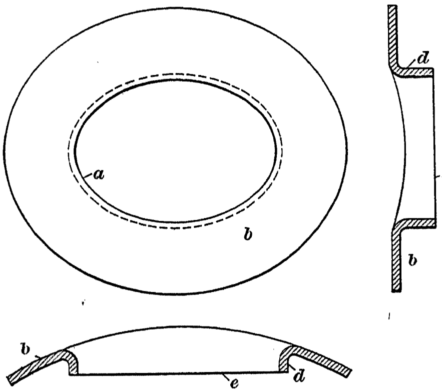


FIG. 54

56. In the perspective, Fig. 55, is shown an assembly of a manhole plate, reinforcing ring, and crab made of pressed steel. It will be noticed that only one crab is employed, thus making a light form of manhole cover installation. When a manhole is placed in a head, the sheet is usually flanged inwards, the flange serving to stiffen the metal around the opening. A flat manhole cover and other details for attaching the cover-plate in position are made like those already described. The manhole plates may be made of wrought steel or steel castings; cast iron is not suitable for pressure vessels. The least width of bearing surface for a manhole gasket is $\frac{1}{2}$ inch and the gasket should not be over $\frac{1}{4}$ inch thick.

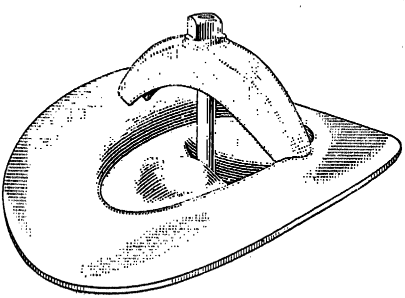


FIG. 55

WATER AND STEAM-PIPE OPENINGS

57. Reinforcement of Pipe Openings.—If water pipes or steam pipes that enter the head, shell, dome, etc., of a boiler are rather small and the plate is relatively thick, they may be screwed directly into the plate; but if such pipes are comparatively large, the plate must be reinforced where the pipes enter. The manner in which plates are reinforced at pipe openings depends somewhat on the size of the pipe and the thickness of the plate, and, in case a boiler fitting is attached, on the character of the fitting. The respective boiler rules specify how the pipe openings and other fitting connections should be reinforced. The A. S. M. E. Boiler Code contains the following requirements as to pipe connections to boilers: "If the thickness of the material in the boiler is not sufficient to give the required number of threads in accordance with Table I, the opening shall be reinforced by a pressed-steel, cast-steel, or bronze-composition flange, or plate, so as to provide the thickness of plate for the required number of threads."

TABLE I

MINIMUM NUMBER OF PIPE THREADS FOR BOILER CONNECTIONS

Size of Pipe Connection Inches	Number of Threads per Inch	Minimum Number of Threads Required in Opening	Minimum Thickness of Material Required Inches
1 and 1¼	11½	4	.348
1½ and 2	11½	5	.435
2½ to 4	8	7	.875
4½ to 6	8	8	1.000
7 and 8	8	10	1.250
9 and 10	8	12	1.500
12	8	13	1.625

58. Reinforcing Small Pipe Openings.—Small openings that are to be tapped for pipes not exceeding 1½ inches nominal diameter usually have the holes reinforced with a triangular liner *a*, Fig. 56, which is riveted to the inside of the shell plate

as shown. The sectional view is taken on the line *A A* of the front view.

In horizontal tubular boilers having the blow-off attached to the bottom of the rear course, the hole is reinforced by an out-

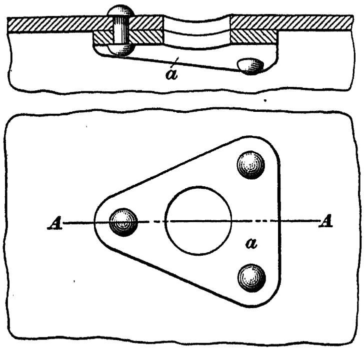


FIG. 56

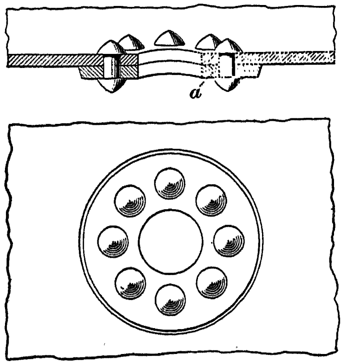


FIG. 57

side circular liner *a*, Fig. 57, attached to the boiler sheet by several rivets; flanges of the form shown in Fig. 58 are also used extensively, being riveted to the shell and calked. Connections for feedwater piping are made in this manner. This form of flange permits the pipe to be screwed in from each side and in addition reinforces the metal around the opening. The minimum size of pipe and fittings for blow-off piping is 1 inch,

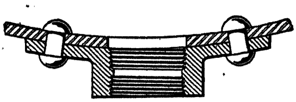


FIG. 58

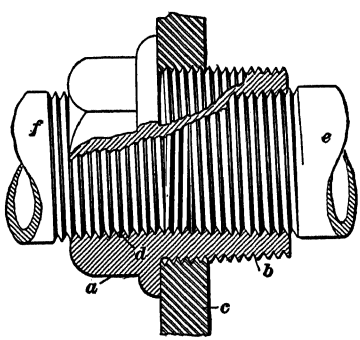


FIG. 59

and the maximum size is not over $2\frac{1}{2}$ inches in diameter. Brass or steel bushings *a*, Fig. 59, are used for attaching feedwater piping up to and including pipes $1\frac{1}{2}$ inches in size. The bushing is threaded on the outside at *b* so as to enter the threaded

opening in the plate *c*. The internal thread *d* permits turning the feed-pipes *e* and *f* into position. In tubular boilers, bushings of this kind are used extensively, being secured to the front head of the boiler and calked to prevent any possibility of leakage.

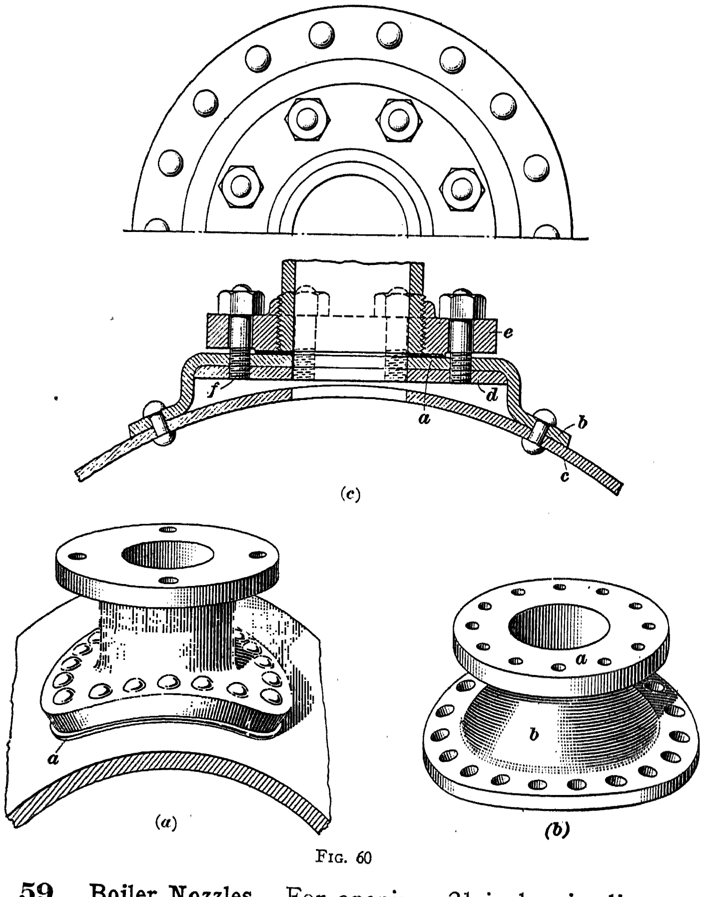


FIG. 60

59. Boiler Nozzles.—For openings $2\frac{1}{2}$ inches in diameter and larger it is necessary to use flanged fittings called *nozzles*. Such fittings are made of steel or iron castings of the form shown in Fig. 60 (*a*), or of pressed steel of the form shown in (*b*). The latter construction is the stronger and is best

suited for boiler-fitting connections. If cast steel or iron nozzles are used, the requirements governing their use and manufacture must be complied with. The A. S. M. E. Boiler Code does not permit the use of cast-iron fittings for pressure parts over 2 inches in diameter, for pressures above 160 pounds per square inch. For fittings of this kind up to and including 160 pounds per square inch, the nozzles must conform to the American Manufacturers' standard, except that in the case of nozzles for safety valves the face of the safety valve and nozzle may be made flat. In some cases the flange faces are made with a raised face that is machined to provide a straight bearing surface between the connecting fittings. Some authorities prohibit the use of cast iron for this purpose, owing to its low tensile strength and its liability to be in a weakened condition due to a porous formation of the metal in molding.

60. Pressed-steel nozzles, also referred to as saddle flanges, are made of the shapes shown in Fig. 60 (*b*) and (*c*). In either form the nozzle is pressed from steel plate to form the face *a* for the seat of the connecting fitting and the base *b* to conform to the shape of the boiler shell *c*. This form of construction produces a very strong fitting. The saddle shown in (*c*) is reinforced with a liner *d* of the same plate thickness, which is usually welded at four points to the saddle. To hold the pipe flange *e*, studs *f* are screwed into the plate *d* and the metal of the saddle. Both types of nozzles are beveled so that they can be calked. In the case of a cast nozzle, as in (*a*), a copper or steel strip *a* is placed between the nozzle and the plate for calking purposes.

BOILER DETAILS
(PART 2)

STAYING

TYPES OF STAYS AND BRACES

PURPOSE AND CLASSIFICATION

1. Introduction.—The terms *stay* and *brace* are applied to boiler details designed to support plates not strong enough in themselves to resist safely the steam pressure that the boiler is intended to carry. A stay or brace may be in tension or in compression, depending on the method of installation. Cylindrical shells, hemispherical heads, and spherical shapes subjected to internal pressure are self-supporting, as the pressure tends to maintain the curved forms; therefore, boiler plates of such forms and of sufficient thickness need no staying. Curved sections that cannot be made thick enough to sustain the steam pressure must be stayed.

Internal or external pressure acting on a flat plate tends to distort the metal to a spherical form; hence, a flat plate is not self-supporting, as it cannot be made sufficiently thick to prevent undue deformation. It is advantageous to use light boiler plate and stay it to withstand safely the given pressure.

2. Classification of Stays.—Stays used for bracing steam boilers may be divided into three general classes; namely, *direct stays, diagonal stays,* and *girder stays.*

A direct stay is one in which the load due to the steam pressure is applied directly in line with the axis of the stay. In